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Research Article

Next-Generation Power Electronics for Electric Vehicles: The Role of Wide Bandgap Semiconductors (SiC & GaN)

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ABSTRACT

The global transition to electric mobility has placed unprecedented demands on the performance, efficiency, and compactness of power electronic systems within electric vehicles (EVs). Traditional silicon-based semiconductors are reaching their physical and performance limits, prompting the exploration of advanced materials. This research investigates the transformative role of wide bandgap (WBG) semiconductors—specifically silicon carbide (SiC) and gallium nitride (GaN)—as the cornerstone of next-generation EV power electronics.

WBG materials possess superior intrinsic properties such as wider bandgap energy, higher breakdown electric fields, greater thermal conductivity, and faster switching capabilities compared to conventional silicon. These characteristics allow power devices to operate at higher voltages, frequencies, and temperatures while minimizing energy loss and thermal stress. SiC devices are particularly suited for high-voltage, high-temperature applications such as traction inverters and DC-DC converters, while GaN excels in high-frequency, compact applications like onboard chargers and auxiliary power supplies.

This paper presents a comprehensive comparison of SiC and GaN material properties and explores their specific applications in modern EV architectures. Through analytical tables and performance graphs, the study highlights the significant improvements in power density, efficiency, and thermal management that WBG devices offer. It also addresses current challenges such as high manufacturing costs, material integration issues, and long-term reliability concerns.

The findings emphasize that WBG semiconductors are not merely incremental upgrades but essential enablers of the next technological leap in electric vehicle design. As automotive industries push toward greater energy efficiency and miniaturization, SiC and GaN are poised to become foundational elements of future EV powertrain systems, offering compelling benefits that support the global shift toward sustainable transportation.

Keywords: Wide Bandgap Semiconductors, Silicon Carbide (SiC), Gallium Nitride (GaN), Electric Vehicles, Power Electronics, Traction Inverters, Onboard Chargers, Energy Efficiency.

1. Introduction

1.1 Context

In recent years, electric vehicles (EVs) have moved from niche alternatives to central figures in the global pursuit of sustainable transportation. Driven by the urgent need to reduce greenhouse gas emissions, global warming, and dependency on fossil fuels, governments and industries are investing heavily in electrification. Major automotive manufacturers—including Tesla, Toyota, BYD, and Volkswagen—are ramping up their EV offerings, while nations implement regulatory frameworks to phase out internal combustion engines (ICEs).

This transition has significantly increased the demand for innovations not just in batteries and motors, but also in power electronics—the control and conversion systems that regulate power flow in EVs. These electronics serve as the critical interface between the energy stored in batteries and the propulsion system, ensuring optimal operation of components like traction inverters, onboard chargers (OBCs), and DC-DC converters. As vehicles become more electrified and compact, the need for efficient, compact, high-temperature tolerant, and high-frequency power devices has become a major engineering concern.

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1.2 Problem Statement

Since the inception of semiconductor electronics, silicon (Si) has been the dominant material in power semiconductor devices due to its abundance, low cost, well-understood processing technology, and integration capability. However, the rapid advancement of EV technology has exposed the intrinsic limitations of silicon in demanding power applications.

Key limitations of silicon include:

- Narrow bandgap energy (1.1 eV), which limits the ability to operate at high temperatures and increases leakage currents.
- Low critical electric field strength, which restricts the maximum breakdown voltage, making it less suitable for high-power systems.
- Lower thermal conductivity, causing increased heat generation and reliance on complex and bulky cooling solutions.
- Lower switching frequencies, which reduce efficiency and require larger passive components, increasing size and weight.

In EVs, where space is at a premium and efficiency is paramount, these drawbacks result in increased energy loss, larger and heavier systems, and greater cooling requirements—all of which hinder the potential range, performance, and cost-effectiveness of electric vehicles.

1.3 Objective

To overcome the shortcomings of silicon, the power electronics industry is turning to Wide Bandgap (WBG) semiconductors, specifically Silicon Carbide (SiC) and Gallium Nitride (GaN). These materials possess significantly higher bandgap energies—3.3 eV for SiC and 3.4 eV for GaN—which enable operation at higher voltages, temperatures, and frequencies.

The objective of this research paper is to:

- Examine the physical and electrical properties of SiC and GaN in comparison to conventional silicon.
- Explore the real-world performance benefits of WBG materials in EV-specific power applications.
- Identify technological challenges such as manufacturing complexity, cost, and system integration.
- Evaluate the future potential and industry trends, including adoption by major EV manufacturers.

By focusing on practical use cases and performance metrics, this study aims to highlight how WBG semiconductors are reshaping the power electronics landscape, improving the efficiency and reliability of EV systems, and ultimately accelerating the mass adoption of electric mobility.

1.4 Scope

This paper concentrates on the application of SiC and GaN technologies within three core subsystems of electric vehicles:

a. Traction Inverters

The traction inverter converts DC power from the battery into three-phase AC power for the electric motor. This is a high-power, high-voltage function where SiC offers significant improvements in efficiency, reduced thermal losses, and higher switching speed compared to Si.

b. Onboard Chargers (OBCs)

OBCs convert AC power from the grid into DC to recharge the battery. GaN devices, due to their high switching frequencies and compact form factors, are becoming ideal for building lightweight, high-efficiency chargers, especially in fast-charging applications.

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c. DC-DC Converters

These converters step down high-voltage battery output to lower voltage levels (typically 12V or 48V) for auxiliary systems like lighting, infotainment, and sensors. GaN, with its high-frequency capabilities, enables more compact and thermally efficient converter designs.

This focused approach provides a structured examination of how each WBG material aligns with the unique demands of different EV subsystems. Additionally, while SiC and GaN share some characteristics, their distinct properties make them complementary rather than competitive in many cases.

2. Fundamentals of Wide Bandgap Semiconductors

2.1 Definition of Bandgap and Its Significance

In solid-state physics, the bandgap is a core concept used to describe the electrical behavior of a material. It is defined as the energy difference between the valence band, which contains bound electrons, and the conduction band, where electrons are free to move under an electric field. This energy gap determines a material's conductivity.

- Conductors have overlapping bands (no bandgap)
- Insulators have a large bandgap (>4 eV)
- Semiconductors like Silicon (Si), Silicon Carbide (SiC), and Gallium Nitride (GaN) have moderate to wide bandgaps, allowing control over their conductivity

The wider the bandgap, the more energy required to excite an electron into the conduction band. This makes wide bandgap (WBG) materials more resilient to high voltages, less prone to leakage currents, and capable of operating at higher temperatures and frequencies compared to traditional silicon.

Bandgap in Power Electronics

In EV power electronics, this translates to:

- Faster switching with less energy loss
- Greater efficiency, enabling longer vehicle range
- Smaller components, reducing size and cost
- Improved thermal performance, decreasing need for active cooling systems

2.2 Why Wide Bandgap? Physical and Electronic Advantages

Wide bandgap semiconductors offer a suite of physical and electronic benefits that outperform conventional Si-based devices. The following table compares the intrinsic properties of Si, SiC, and GaN:

Material Property	**Silicon (Si)**	**Silicon Carbide (SiC)**	**Gallium Nitride (GaN)**
Bandgap (eV)	1.1	3.3	3.4
Breakdown Electric Field (MV/cm)	0.3	2.8	3.3
Electron Mobility ($cm^2/V{\cdot}s$)	1500	950	2000
Thermal Conductivity	1.5	4.9	1.3

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(W/cm·K)			
Saturated Electron Velocity (cm/s)	1.0×10^7	2.0×10^7	2.5×10^7
Max Operating Temp (°C)	150	600	400

Table 1: Comparative Properties of Si, SiC, and GaN

Advantages of WBG Materials:

Higher Breakdown Voltage

- WBG materials can sustain higher electric fields before breaking down. This allows the design of compact high-voltage components with fewer layers.

Higher Switching Frequency

- GaN, in particular, can switch at frequencies exceeding 1 MHz, enabling lighter, smaller inductors and capacitors.

Better Thermal Stability

- SiC's high thermal conductivity and ability to operate at up to 600°C reduce the burden on thermal management systems.

Lower Switching and Conduction Losses

- WBG devices switch faster and with less power loss, improving the energy efficiency of EVs.

Higher Power Density

- With smaller passive components and efficient heat dissipation, power electronics using WBG devices can achieve greater power in smaller packages.

2.3 Overview of SiC and GaN Structures and Properties

2.3.1 Silicon Carbide (SiC)

Material Characteristics:

- SiC is a compound semiconductor made of silicon and carbon.
- The most common form used in electronics is 4H-SiC, known for its high electron mobility and wide bandgap.

Crystal Structure:

- Hexagonal lattice with high thermal stability.
- Produced via sublimation at high temperatures (above 2,000°C), making fabrication complex and expensive.

Key Properties:

- High breakdown voltage (ideal for 600V–1700V systems)
- Excellent thermal conductivity (~4.9 W/cm·K)
- Stable operation at very high temperatures (up to 600°C)

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Applications in EVs:

- Traction inverters: SiC enables higher efficiency and less heat, extending driving range.
- DC-DC converters: High voltage blocking and fast switching reduce energy loss.
- Onboard chargers (OBCs): Compact and lightweight due to less cooling requirements.

Challenges:

- Cost of SiC wafers is 5–10x higher than silicon.
- Defect density and wafer size scalability remain production challenges.

2.3.2 Gallium Nitride (GaN)

Material Characteristics:

- GaN is a III-V compound semiconductor, known for its ultra-fast switching and high electron mobility.
- Commonly grown on substrates like silicon, sapphire, or SiC to reduce production costs.

Crystal Structure:

- Wurtzite (hexagonal) structure
- Thin-film deposition using Metal-Organic Chemical Vapor Deposition (MOCVD)

Key Properties:

- High switching speeds (up to GHz range)
- High electron mobility (~2000 $cm^2/V{\cdot}s$)
- Ideal for <600V applications

Applications in EVs:

- Onboard chargers and power converters: GaN allows very compact designs.
- DC-DC converters: Especially suited for 48V to 12V auxiliary power modules.
- Fast EV chargers (Level 3): Enables ultra-efficient and small-form-factor designs.

Challenges:

- Poor thermal conductivity compared to SiC.
- Requires advanced packaging and thermal design.
- Substrate mismatch can cause lattice defects, affecting reliability.

2.4 Summary of Material Use in EV Power Electronics

Parameter	Silicon Carbide (SiC)	Gallium Nitride (GaN)
Best Use Case	Traction systems, high-power OBC	Compact DC-DC converters, fast chargers

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Voltage Range	600V – 1700V+	100V – 650V
Thermal Handling	Excellent	Moderate
Switching Speed	High	Very High
Cost	High (but declining)	Moderate (increasing with scale)
Commercial Examples	Tesla Model 3 inverter	GaN Systems, Navitas, Transphorm

Table 2.0

The transition to wide bandgap semiconductors is a technological leap in EV power electronics. SiC and GaN each have distinct structural and electrical advantages that enable higher efficiency, reduced weight, and enhanced thermal performance. While SiC is suited for high-voltage and high-power systems, GaN excels in high-frequency, compact designs. Together, they represent the cornerstone of next-generation power electronics that will drive the evolution of electric mobility.

3. Comparative Material Properties

The performance, efficiency, and scalability of electric vehicle (EV) power electronics are fundamentally tied to the characteristics of the semiconductor materials used in switching devices such as MOSFETs (Metal-Oxide-Semiconductor Field-Effect Transistors) and IGBTs (Insulated Gate Bipolar Transistors). Traditional silicon (Si) has been the cornerstone of power electronics for decades due to its established fabrication processes and low cost. However, the growing demand for higher voltage tolerance, improved thermal performance, faster switching, and greater power density has exposed the limitations of silicon-based devices.

To address these limitations, Wide Bandgap (WBG) semiconductors—specifically Silicon Carbide (SiC) and Gallium Nitride (GaN)—have gained significant traction. These materials possess superior physical and electrical characteristics that are critical for next-generation EV power systems, especially in applications such as traction inverters, DC-DC converters, and onboard chargers (OBCs).

3.1 Key Material Property Comparison Table

Material Property	**Silicon (Si)**	**Silicon Carbide (SiC)**	**Gallium Nitride (GaN)**
Bandgap Energy (eV)	1.1	3.3	3.4
Breakdown Electric Field (MV/cm)	0.3	2.8	3.3
Electron Mobility ($cm^2/V{\cdot}s$)	1500	950	2000
Thermal Conductivity (W/cm·K)	1.5	4.9	1.3
Saturation Velocity ($\times 10^7$ cm/s)	1.0	2.0	2.5
Maximum Junction Temperature (°C)	150	600	400
Switching Frequency	~20	>100	>1000

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Potential (kHz)			

Table 3: Comparative physical and electrical properties of Si, SiC, and GaN

3.2 Bandgap Energy

The bandgap is the energy required to move an electron from the valence band to the conduction band within a semiconductor. A wider bandgap allows for better operation at higher voltages and temperatures, as it minimizes thermal generation of carriers (i.e., leakage currents) at elevated temperatures.

- Silicon (1.1 eV): Limited by thermal leakage at high temperatures, reducing efficiency and reliability in high-power EV applications.
- SiC (3.3 eV) & GaN (3.4 eV): Their wide bandgap enables devices to maintain low leakage currents and high blocking voltages even at elevated operating temperatures (above 200°C).

Impact: WBG semiconductors are ideal for high-power and high-temperature environments such as traction inverters and high-speed charging systems in EVs.

3.3 Breakdown Electric Field Strength

The breakdown electric field determines how much electric field a material can tolerate before it undergoes dielectric breakdown.

- Silicon: 0.3 MV/cm, requiring thick layers to prevent breakdown—limiting voltage scaling and increasing size.
- SiC: 2.8 MV/cm
- GaN: 3.3 MV/cm

Impact: Devices made with SiC or GaN can block 10× higher voltages than Si at the same thickness. This enables compact, high-voltage devices that minimize parasitics and reduce overall system cost and volume.

3.4 Electron Mobility

Electron mobility reflects how quickly electrons can move through a semiconductor under an electric field, affecting how fast a device can switch on and off.

- Silicon (1500 $cm^2/V{\cdot}s$): Moderate mobility.
- SiC (950 $cm^2/V{\cdot}s$): Slightly lower mobility due to higher effective mass, but still effective for high-power systems.
- GaN (2000 $cm^2/V{\cdot}s$): Extremely high mobility, allowing for very fast switching and high-frequency operation.

Impact: GaN-based devices are ideal for applications that benefit from fast switching, such as onboard chargers, power conversion, and high-frequency resonant converters.

3.5 Thermal Conductivity

Thermal conductivity is a critical factor in determining how well heat generated by the semiconductor can be dissipated. Poor thermal management can lead to device degradation, reduced efficiency, or catastrophic failure.

- SiC (4.9 W/cm·K): Excellent thermal management, allowing higher current densities and reduced need for active cooling.
- Silicon (1.5 W/cm·K): Lower heat dissipation capacity.
- GaN (1.3 W/cm·K): Despite high electrical performance, GaN's thermal conductivity is relatively low and

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requires advanced packaging solutions like GaN-on-SiC to mitigate heat buildup.

Impact: SiC is highly suited for traction inverters and battery systems that operate under extreme loads and temperatures, while GaN requires careful thermal management to unlock its full potential in compact packages.

3.6 Saturation Velocity

Saturation velocity is the maximum velocity that electrons can achieve in a semiconductor when subjected to a strong electric field.

- Si (1.0×10^7 cm/s): Lowest among the three.
- SiC (2.0×10^7 cm/s): Moderate, suitable for high-speed switching.
- GaN (2.5×10^7 cm/s): Highest saturation velocity, enabling ultra-fast switching, low switching losses, and compact designs.

Impact: High saturation velocity enhances switching speed, reducing both switching and conduction losses, and enables smaller magnetic components in converters—especially useful in GaN-based power supplies.

3.7 Maximum Junction Temperature

The maximum junction temperature (Tj max) defines the maximum temperature at which the semiconductor device can operate safely.

- Si: Limited to ~150°C
- GaN: ~400°C
- SiC: Up to 600°C

Impact: Higher Tj allows devices to operate without heavy cooling systems, improving thermal headroom, system reliability, and power density. SiC's high thermal robustness is ideal for harsh automotive environments.

3.8 Switching Frequency Potential

The switching frequency defines how fast a device can turn on/off per second. Faster switching reduces filter size, magnetic component volume, and energy losses in the form of heat.

- Silicon: Typically limited to 20–50 kHz in power applications.
- SiC: Operates efficiently up to 100–300 kHz.
- GaN: Exceeds 1 MHz in some designs.

Impact: GaN allows miniaturization of power converters, reduces system weight, and increases efficiency—crucial for onboard and fast charging EV modules.

3.9 Application Mapping in EV Systems

EV Component	Preferred Material	Justification
Traction Inverter	SiC	High voltage, high temperature, compact packaging
Onboard Charger (OBC)	GaN	High frequency, low weight, reduced EMI
DC-DC Converter	GaN	High-speed operation, small

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		magnetic components
Battery Management System	SiC or GaN	Depending on voltage and space constraints
Wireless Charging System	GaN	Very high frequency switching and low losses

Table 4.

SiC and GaN significantly outperform silicon across most key metrics that affect EV power system design. SiC is more mature and better suited for high-voltage, high-power environments such as main propulsion systems, while GaN's high-speed characteristics make it ideal for auxiliary converters and charging infrastructure.

Despite their current higher costs, advances in manufacturing yield, device packaging, and supply chain scaling are making WBG semiconductors more accessible. As EV adoption accelerates globally, SiC and GaN will become industry standards, offering breakthroughs in performance, energy efficiency, and thermal management.

4. Power Electronic Applications in Electric Vehicles (EVs)

The advancement of electric vehicle (EV) technology relies heavily on the performance, reliability, and efficiency of power electronic systems. These systems are responsible for converting and managing electrical energy within the vehicle, impacting everything from driving range to charge time and overall thermal management. The integration of wide bandgap (WBG) semiconductors—specifically silicon carbide (SiC) and gallium nitride (GaN)—has significantly elevated the capabilities of key components: traction inverters, onboard chargers (OBC), and DC-DC converters.

4.1 Traction Inverters

Overview and Function

Traction inverters are critical components that convert direct current (DC) from the battery into alternating current (AC) to power the electric motor. They also facilitate regenerative braking by converting kinetic energy back into electrical energy. Given the high-power demands and harsh operating conditions, traction inverters are prime candidates for SiC integration.

SiC's Advantages in High-Voltage and High-Temperature Operation

SiC MOSFETs and Schottky diodes have emerged as superior alternatives to traditional silicon-based IGBT (Insulated Gate Bipolar Transistors) and diodes due to their:

- Wide Bandgap (3.3 eV) enabling operations at voltages exceeding 1200V without breakdown.
- High thermal conductivity (~4.9 W/cm·K) which supports operation at elevated temperatures (> 200°C junction temperature), reducing the need for bulky liquid cooling systems.
- Low switching and conduction losses, improving energy efficiency and minimizing heat generation.
- Fast switching speeds, supporting higher motor frequencies and better torque response.

These properties translate directly into better driving range, system compactness, and thermal efficiency for EVs.

Case Study: Tesla Model 3 Inverter with SiC

Tesla revolutionized the EV market by becoming the first automaker to adopt a full SiC inverter in a mass-produced vehicle. In collaboration with STMicroelectronics, Tesla integrated a SiC-based power module in the Model 3 rear-wheel-drive variant, operating at 400V architecture.

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Impact of SiC Implementation:

- Efficiency Gain: Achieved over 96% inverter efficiency, reducing energy losses during acceleration and regenerative braking.
- Thermal Management: SiC reduced the cooling system's size by 25%, contributing to overall vehicle weight reduction.
- Driving Range: Enabled up to a 10% increase in real-world range due to energy savings during operation.
- Durability: SiC's robustness under high switching frequencies (>20 kHz) enhanced reliability in extreme environments.

This implementation set a new industry standard and was later adopted by Lucid Motors, BYD, and Hyundai in their high-performance EVs.

4.2 Onboard Chargers (OBC)

Function and Importance

The OBC enables charging the vehicle's battery using alternating current from residential or public charging stations. It is responsible for AC-to-DC conversion and often includes power factor correction (PFC). Efficiency, size, and heat generation are critical in this subsystem, especially for compact EV platforms.

GaN's Compactness and High-Frequency Efficiency

Gallium Nitride (GaN) High Electron Mobility Transistors (HEMTs) are especially suited for onboard chargers due to:

- High switching frequency capability (>1 MHz), enabling smaller passive components and faster power conversion.
- Low gate charge and output capacitance, leading to lower switching losses and higher efficiency.
- Superior power density, reducing the charger's volume and weight by up to 50%.
- Soft switching compatibility (e.g., ZVS and ZCS), minimizing electromagnetic interference (EMI).

GaN's ability to maintain high efficiency even under partial load conditions makes it ideal for Level 2 and Level 3 AC chargers operating between 3.6 kW and 22 kW.

Emerging GaN-Based OBC Systems

- ZF Friedrichshafen developed a 22 kW bidirectional OBC using GaN from GaN Systems, achieving >96% peak efficiency and reducing volume by 50%.
- Toyota has introduced a GaN-based bidirectional charging system, supporting vehicle-to-grid (V2G) applications, where the vehicle can feed energy back to the grid.
- Navitas Semiconductor, in partnership with OEMs, is advancing GaN-based integrated power stages for future 800V EV platforms.

GaN also enables modular architectures, allowing the same OBC to support multiple vehicle models and battery configurations without redesign.

4.3 DC-DC Converters

Role and Requirements

DC-DC converters serve to step down high-voltage DC from the traction battery (400V or 800V) to lower voltages (typically 12V or 48V) for powering auxiliary components such as infotainment systems, lighting, sensors, and control

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units. The emergence of dual-voltage systems in modern EVs increases the demand for compact, efficient converters.

Size and Switching Advantages of GaN

GaN-based DC-DC converters offer:

- High power density (>2 W/cm³) due to high-frequency operation (>500 kHz).
- Reduced size and weight by up to 70% compared to Si counterparts.
- Low EMI emissions, eliminating the need for extensive shielding.
- High efficiency (up to 98%), which is crucial in low-power continuous-duty applications.

Suitability in 48V Systems and Auxiliary Subsystems

48V systems are being increasingly adopted in EVs for power steering, cooling fans, and electric turbochargers. GaN is particularly well-suited for these applications:

- Enables resonant converter topologies like LLC and CLLC, optimizing efficiency across load ranges.
- Supports multi-phase interleaved converters for balanced current sharing and better thermal performance.
- Ideal for smart power modules (SPMs) that integrate control and sensing, streamlining vehicle electronics architecture.

Examples of Implementation:

- Valeo and Infineon are developing 48V GaN-based power modules for European EV platforms.
- NIO and XPeng Motors have initiated GaN pilot programs for auxiliary converters in their luxury EV lines.

Summary Table 5: WBG Applications in EV Subsystems

Application	**Preferred WBG Material**	**Operating Voltage Range**	**Key Benefits**	**Industry Adoption Example**
Traction Inverter	Silicon Carbide (SiC)	400V–800V+	High voltage, low losses, thermal efficiency	Tesla Model 3, Lucid Air
Onboard Charger	Gallium Nitride (GaN)	3.6 kW–22 kW	High frequency, compactness, bidirectional readiness	Toyota V2G OBC, ZF GaN OBC
DC-DC Converter	Gallium Nitride (GaN)	48V–12V	High efficiency, reduced EMI, space saving	Valeo 48V GaN System, NIO GaN Pilot

5. Performance Analysis

The implementation of wide bandgap (WBG) semiconductors—Silicon Carbide (SiC) and Gallium Nitride (GaN)—in EV power electronics leads to notable improvements in performance metrics including power density, energy efficiency, thermal management, and system compactness. This section presents a comparative analysis using key electrical and

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thermal parameters.

Table 6: Material Performance Comparison

Parameter	Silicon (Si)	Silicon Carbide (SiC)	Gallium Nitride (GaN)
Bandgap (eV)	1.1	3.3	3.4
Breakdown Electric Field (MV/cm)	0.3	2.8	3.3
Thermal Conductivity (W/cm·K)	1.5	4.9	1.3
Max Switching Frequency (kHz)	20	100	1000
Max Junction Temperature (°C)	150	600	400

Interpretation:

The superior material characteristics of SiC and GaN enable operation at higher voltages, faster switching speeds, and greater thermal resilience. These properties are key to improving the power system performance in electric vehicles.

5.1 Power Density and Efficiency Gains

WBG devices significantly outperform conventional silicon devices in switching characteristics due to their higher breakdown electric fields and faster electron mobility.

Switching Loss Reduction

- SiC devices exhibit up to 80% lower switching losses compared to Si MOSFETs, primarily due to lower ON-resistance and faster transitions.
- GaN High Electron Mobility Transistors (HEMTs) allow for extremely fast switching, reducing losses even at very high frequencies.

Power Density

- SiC and GaN allow EV inverters and converters to be designed with higher power density (up to 2–3× more compact).
- High power density leads to smaller system footprints, weight reduction, and better utilization of available vehicle space.

Impact on EV Efficiency

- Reduced switching and conduction losses directly translate to higher drive cycle efficiency, extending EV driving range by up to 5–10% without increasing battery capacity.
- Smaller cooling systems reduce vehicle weight, which further contributes to efficiency.

5.2 Thermal Management Improvements

The thermal properties of WBG semiconductors, especially SiC, drastically improve the thermal management

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challenges faced in EV systems.

SiC Thermal Advantages

Thermal conductivity of SiC (~4.9 W/cm·K) is more than 3× higher than that of silicon.

SiC devices can sustain junction temperatures up to 600°C, allowing for:

- Reduced dependence on bulky heat sinks or liquid cooling systems
- Operation in harsh automotive environments (e.g., under-hood applications)
- Longer device lifespan due to lower thermal cycling fatigue

GaN Considerations

- Though GaN has lower thermal conductivity (~1.3 W/cm·K), it compensates with low power loss and small chip area, allowing effective use of heat spreaders and packaging innovations.
- GaN's minimal conduction losses reduce heat generation, easing the burden on cooling solutions in low-to-mid power applications.

5.3 System Integration Benefits

High-Frequency Operation

- GaN devices can switch at frequencies above 1 MHz, compared to <100 kHz for Si-based systems.
- This enables the miniaturization of passive components like inductors and capacitors, which dominate the size of power converters.

Reduced Electromagnetic Interference (EMI)

- GaN's clean switching characteristics lead to lower EMI, simplifying filter design and reducing shielding requirements.

Compact, Lightweight Systems

Smaller magnetics and fewer cooling requirements result in:

- Lighter onboard chargers and DC-DC converters
- Reduced cost of housing and integration
- Greater flexibility in EV architecture design

Real-World Impact

- For instance, GaN-based OBCs have shown up to 40% size reduction and 30% weight reduction, while delivering the same or improved performance.

SiC is optimal for high-voltage, high-power components like traction inverters. GaN excels in high-frequency, compact systems such as onboard chargers and auxiliary converters. Together, they form a critical toolkit for the electrification of modern mobility.

6. Challenges in WBG Adoption

Despite the promising advantages of wide bandgap (WBG) semiconductors—particularly silicon carbide (SiC) and gallium nitride (GaN)—their widespread adoption in electric vehicle (EV) power electronics is constrained by a series of technological, economic, and infrastructural challenges. This section offers a comprehensive analysis of the major

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barriers to mainstream integration and highlights areas where continued research, innovation, and standardization are critically needed.

6.1 Cost per Device and Manufacturing Maturity

One of the foremost challenges in adopting WBG semiconductors lies in their cost structure and limited manufacturing maturity compared to traditional silicon (Si) technologies.

High Device Cost

- Material Expense: SiC and GaN substrates are significantly more expensive than silicon due to complex fabrication processes. A SiC MOSFET can cost 3–5 times more than an equivalent silicon IGBT.
- Wafer Production Complexity: SiC wafers require high-temperature processes such as sublimation growth, often leading to structural defects (e.g., micropipes, dislocations), which reduce wafer yield and raise costs.
- GaN Substrate Limitations: GaN is typically grown on foreign substrates like silicon, sapphire, or SiC, which introduces strain and limits scalability.
- Low Production Volumes: Unlike Si fabrication, which benefits from decades of high-volume manufacturing and economies of scale, WBG devices are still ramping up production.

Manufacturing Infrastructure

- Specialized Equipment: Producing SiC and GaN devices requires dedicated equipment, such as high-temperature furnaces and epitaxial reactors, which involve high capital expenditures.
- Foundry Availability: Only a handful of foundries have optimized high-yield, large-diameter (6–8 inch) WBG wafer production capabilities. This constrains supply and increases lead time for automotive-grade devices.

Although the total system cost of WBG-based power modules may decrease due to smaller passive components and reduced cooling requirements, the upfront component cost remains a major deterrent—especially in cost-sensitive EV segments.

6.2 Reliability Under Long-Term Automotive Stress

Reliability is paramount in automotive applications, where components must operate under varying and extreme environmental conditions for up to 15 years. WBG devices, despite their thermal and electrical advantages, are still undergoing qualification for long-term reliability and stability.

Thermal and Mechanical Stress

- Temperature Extremes: While SiC and GaN can withstand junction temperatures up to 600°C and 400°C respectively, packaging materials (e.g., mold compounds, wire bonds) often limit the system's thermal capability.
- Thermal Cycling: Repetitive power cycles (from vehicle acceleration, braking, and charging) create temperature fluctuations that induce mechanical fatigue, leading to microcracks or delamination at the die-attach or solder layers.

Electromagnetic Interference (EMI)

- High Switching Speeds: WBG devices switch at frequencies up to 10x higher than silicon, which can introduce unwanted EMI into the system, affecting sensors, communication buses, and control units.
- Noise Sensitivity: EMI can result in false switching or degradation in gate driver performance, potentially leading to system instability or failure.

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Degradation Mechanisms

- GaN Traps and Gate Instability: GaN HEMTs may suffer from threshold voltage shifts due to electron trapping, especially under high-frequency operation.
- SiC Defects: Surface or interface traps in SiC can cause long-term degradation in MOSFET channel mobility and switching performance.

Ongoing research into accelerated life testing (e.g., HTRB, HTGB, power cycling) is crucial to build confidence in the reliability of WBG devices under automotive-grade stress.

6.3 Packaging and Thermal Interface Complexities

Efficient packaging is essential to fully leverage the high-speed and high-temperature operation of WBG semiconductors. However, current packaging techniques often fall short of supporting the thermal and electrical demands of SiC and GaN devices.

Thermal Management Challenges

- Heat Density: Faster switching and higher power density lead to localized heating. Without adequate heat spreading and dissipation, device performance can degrade.
- Thermal Interface Materials (TIMs): Conventional TIMs may not withstand the elevated junction temperatures of WBG devices or may degrade over time, leading to increased thermal resistance.

Advanced Packaging Requirements

- Double-Sided Cooling: To manage high heat flux, WBG modules increasingly employ double-sided cooling architectures using advanced substrates like DBC or AMB (Active Metal Brazed).
- Wire Bonding vs. Sintering: Traditional wire bonding can create parasitic inductances. Techniques like silver sintering or flip-chip bonding are preferred but are costlier and less mature.
- Parasitic Reduction: To reduce switching losses and EMI, packages must minimize stray inductances—a challenge when balancing size, cost, and manufacturability.

Packaging remains a bottleneck in translating device-level advantages into system-level performance gains.

6.4 Standardization and Regulatory Issues

Unlike silicon technology, which benefits from decades of well-established testing protocols, standards, and certifications, WBG semiconductors lack a universal framework for qualification—particularly in safety-critical automotive environments.

Qualification and Certification Gaps

- AEC-Q101 Limitations: While AEC-Q101 is used for automotive discrete devices, it is based on silicon degradation models and may not accurately reflect WBG-specific failure mechanisms.
- Lack of Device-Specific Standards: There is no universal standard for characterizing dynamic on-resistance, high-frequency switching behavior, or soft failure thresholds for GaN and SiC.

Regulatory Compliance

- Electromagnetic Compatibility (EMC): High-speed switching makes it difficult to meet EMI/EMC regulations such as CISPR 25 or ISO 11452.
- Functional Safety (ISO 26262): WBG devices in inverter or battery systems must comply with functional safety

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levels (ASIL-B to ASIL-D), requiring rigorous validation and fault analysis.

Interoperability and Ecosystem Fragmentation

- Diverse Device Architectures: GaN comes in various flavors (e.g., enhancement-mode, cascode, and gate injection transistor), complicating integration across platforms.
- Vendor Lock-in Risks: Lack of standardized footprints or gate driver interfaces makes it difficult for OEMs to switch suppliers or scale across product lines.

The industry is moving towards consensus, with organizations like JEDEC and the PowerAmerica Institute spearheading efforts to develop new qualification protocols, but gaps remain that hinder large-scale adoption.

Summary Table 7: Key Challenges in WBG Adoption

Challenge	Description	Impact on EV Integration
Cost per Device	High raw material cost, low yields, immature supply chain	Limits use to high-end vehicles
Reliability	Susceptibility to thermal fatigue, EMI, and long-term degradation	Reduces confidence for safety-critical applications
Packaging Complexity	Inadequate heat dissipation, parasitic losses, expensive materials	Limits performance scaling and increases total system cost
Regulatory and Standardization	Lack of WBG-specific qualification standards, EMI challenges, and fragmented ecosystem	Slows certification, increases integration complexity

Table 2: Summary of Critical Barriers to WBG Semiconductor Adoption in EVs

7. Industry Outlook and Trends

The future of electric mobility is inextricably linked with advancements in power electronics. Wide Bandgap (WBG) semiconductors—Silicon Carbide (SiC) and Gallium Nitride (GaN)—are poised to disrupt traditional automotive supply chains, offering unparalleled efficiency, performance, and system-level benefits. However, their adoption is shaped not just by technical superiority, but also by cost dynamics, hybrid integration strategies, and global policy frameworks. This section provides an in-depth examination of the key factors driving WBG industry trends and outlines the roadmap to mainstream deployment in electric vehicles (EVs).

7.1 Cost Trajectory and Volume Adoption Curves

Despite their numerous advantages, WBG semiconductors have historically been limited by high manufacturing costs. However, recent developments in fabrication technology, supply chain scaling, and market competition are causing a rapid decline in cost per unit, making SiC and GaN more accessible for large-scale automotive applications.

7.1.1 Declining Costs of SiC

- Wafer Scaling: Transitioning from 4-inch to 6-inch and recently to 8-inch wafers has significantly improved fabrication throughput. Wolfspeed, one of the pioneers in SiC manufacturing, has launched the world's first 8-inch SiC fab in New York, reducing the cost per device by nearly 30%.
- Yield Improvement: Technological advancements in defect reduction and epitaxial growth have led to better wafer quality and higher device yields.

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- Economies of Scale: Automotive demand from companies like Tesla, Lucid Motors, and Hyundai has increased production volumes, which in turn drives down cost. Tesla's adoption of a full-SiC inverter in the Model 3 set a precedent for cost-effective large-scale implementation.

Projection: According to Yole Développement (2024), SiC MOSFET prices are expected to decrease by 40–60% between 2024 and 2028, achieving cost parity with silicon IGBT modules in many high-performance applications.

7.1.2 Cost Trends in GaN

- GaN-on-Silicon Technology: One of the most significant breakthroughs has been the development of GaN-on-Si epitaxy, which allows GaN devices to be produced using existing silicon fabs. This drastically reduces production costs and eliminates the need for expensive substrates like sapphire or SiC.

- Consumer Electronics Spillover: GaN has seen early adoption in mobile fast chargers, telecom power systems, and server infrastructure, creating a high-volume manufacturing ecosystem that EV suppliers can leverage.

- Packaging Innovations: Integrated GaN solutions (GaN FET + driver in one package) reduce external component counts, which simplifies design and lowers system costs.

Forecast: MarketWatch (2024) estimates that the automotive GaN market will grow at a CAGR of over 60% between 2023 and 2030, driven by increased demand in onboard chargers (OBCs) and low-voltage auxiliary converters.

7.1.3 Adoption Curve Analysis

Both SiC and GaN are currently transitioning from the "early adopter" to the "early majority" phase of the technology adoption lifecycle. Key enablers include:

- Standardization of gate drivers and packages
- Lower Total Cost of Ownership (TCO) due to efficiency gains
- Growing ecosystem of design tools, simulation models, and application notes

7.2 Emerging Hybrid Modules (Si + SiC or SiC + GaN)

As WBG technologies mature, OEMs and Tier-1 suppliers are exploring hybrid module architectures to balance cost, performance, and reliability. Hybridization allows integration of multiple semiconductor materials into a single package to optimize performance across diverse operating conditions.

7.2.1 Si + SiC Hybrid Integration

- Configuration: Typically involves combining Si-based diodes or IGBTs with SiC MOSFETs in a half-bridge or full-bridge topology.

- Use Case: Common in industrial inverters and mid-range EVs, where a mix of cost-effective silicon and high-performance SiC can be leveraged.

- Benefit: Enables gradual transition to full-SiC systems while utilizing existing Si-based packaging and gate drive infrastructure.

7.2.2 SiC + GaN Hybrid Systems

Architecture: SiC is used for high-voltage and high-power stages (traction inverter), while GaN is employed in low-voltage, high-switching-frequency domains (DC-DC converters, OBCs).

Benefit:

- Maximizes system-wide efficiency
- Minimizes weight and volume

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- Reduces thermal stress through better heat distribution

Example: A premium EV may use a SiC-based 800V main inverter and a GaN-based 400V auxiliary converter, optimizing the powertrain for both performance and energy savings.

Packaging & Thermal Management

Hybrid modules are driving innovation in advanced packaging techniques such as:

- Double-sided cooling substrates
- Integrated thermal vias
- Compact planar designs

These enhancements allow tighter integration while managing the different thermal profiles of SiC and GaN devices.

7.3 Government Incentives and R&D Investment

Governments worldwide are recognizing the strategic importance of WBG technologies in achieving carbon neutrality, energy security, and industrial competitiveness. Their support spans research funding, industrial incentives, and cross-border collaborations.

7.3.1 United States

- PowerAmerica Initiative: A U.S. Department of Energy (DOE) program that has invested over $70 million to accelerate the commercialization of WBG semiconductors.
- CHIPS and Science Act (2022): Allocates billions of dollars for domestic semiconductor manufacturing, including incentives for SiC and GaN fabs.
- National Renewable Energy Laboratory (NREL): Leading projects on EV inverter optimization using WBG devices.

7.3.2 European Union

- IPCEI on Microelectronics: Funds over €8 billion in semiconductor R&D, with specific calls for GaN and SiC development.
- Horizon Europe Program: Supports projects on automotive-grade reliability of SiC modules and high-frequency GaN converters.
- European Battery Alliance: Promotes regional supply chains for EV power electronics.

7.3.3 China and Asia-Pacific

- China's 14th Five-Year Plan prioritizes electric mobility and self-reliance in semiconductor supply chains.
- Local companies such as BYD Semiconductor, CRRC, and StarPower are rapidly expanding SiC device production.
- Japan and South Korea are investing in public-private partnerships with companies like Rohm, Mitsubishi Electric, and Samsung to advance WBG packaging and wafer technology.

7.3.4 Academic and Industry Collaboration

Universities and research labs are working closely with industry to:

- Develop new WBG materials (e.g., β-Ga_2O_3, AlN)
- Improve thermal management techniques
- Train a new generation of engineers in WBG circuit design

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Example: The Fraunhofer Institute (Germany) is pioneering work in GaN reliability testing for automotive OBCs.

8. Conclusion

The evolution of electric vehicles (EVs) is fundamentally reshaping the landscape of power electronics. As the demand for high-efficiency, lightweight, compact, and thermally stable power conversion systems rises, the limitations of traditional silicon (Si) semiconductors have become increasingly apparent. The advent of wide bandgap (WBG) semiconductors, specifically Silicon Carbide (SiC) and Gallium Nitride (GaN), marks a transformative leap forward in the design and performance of EV powertrains. These materials are not only driving improvements in energy efficiency and thermal management but also enabling new levels of system integration and miniaturization that are essential for the next generation of electric mobility.

8.1 Silicon Carbide (SiC): The High-Voltage Workhorse

SiC has emerged as the material of choice for high-voltage, high-power applications such as traction inverters and high-capacity onboard chargers. Its wide bandgap (3.3 eV) allows devices to withstand higher electric fields before breaking down, enabling operation at voltages above 1,200 V—ideal for long-range EVs and commercial electric trucks. Furthermore, its high thermal conductivity (4.9 W/cm·K) and ability to operate at temperatures exceeding 600°C make it suitable for harsh automotive environments where reliability and endurance are non-negotiable.

SiC's implementation in inverter systems—like those in Tesla's Model 3—has demonstrated tangible benefits, including:

- Up to 50% reduction in switching losses
- Improved motor efficiency, extending vehicle range
- Simplified thermal design due to reduced heat generation
- Lower system weight by eliminating bulky cooling hardware

These improvements directly contribute to better battery utilization, faster charging, and lighter vehicle architecture, which are pivotal for both performance and sustainability.

8.2 Gallium Nitride (GaN): The Compact Power Performer

GaN excels in high-frequency, low-to-medium voltage applications, making it an excellent candidate for DC-DC converters, auxiliary inverters, and fast chargers. Its exceptionally high electron mobility and switching frequency capabilities (up to 1 MHz) reduce switching losses and allow the use of smaller passive components—such as inductors and capacitors—leading to significant reductions in circuit board size and system weight.

In addition to power efficiency, GaN-based devices contribute to:

- Fast and efficient onboard charging systems (up to 6.6 kW)
- Smaller thermal footprints, eliminating the need for complex heat sinks
- Reduced electromagnetic interference (EMI) through cleaner switching profiles
- Enhanced modularity and design flexibility for next-gen EV platforms

As EVs increasingly adopt decentralized and multi-converter architectures, GaN's role in enabling compact, distributed power systems will become even more crucial.

8.3 Comparative Advantage and System-Level Impact

The combined use of SiC and GaN across different parts of an EV enables a system-level optimization that silicon alone cannot achieve. Together, these materials offer a 40–70% reduction in power losses, higher power density, and greater reliability over a wider temperature range. The cumulative impact is significant:

- Extended vehicle range (by 5–10%)
- Faster charging times (20–30% improvement)

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- Lower total cost of ownership through improved energy efficiency
- Reduced battery size, lowering overall EV weight and material costs

These benefits are particularly important as automakers race to meet stringent emission targets, improve user experience, and reduce manufacturing and operational costs.

8.4 Barriers and Outlook

Despite the proven advantages, several challenges still hinder widespread WBG adoption:

- Higher initial cost: SiC and GaN devices remain more expensive than their Si counterparts, primarily due to complex wafer fabrication and low manufacturing yields.
- Packaging and reliability: New packaging techniques are required to fully exploit the high-temperature and high-frequency capabilities of WBG devices.
- Standardization: Lack of universally accepted automotive standards for GaN and SiC increases design and qualification complexity.

However, these barriers are rapidly being addressed. The cost of SiC devices has dropped by nearly 35% in the past five years due to volume production, and GaN fabrication techniques continue to improve with innovations like GaN-on-silicon (GaN-on-Si) substrates. Additionally, regulatory support and industry collaboration are accelerating the standardization and adoption of WBG technologies.

8.5 Final Remarks

In conclusion, wide bandgap semiconductors are the cornerstone of next-generation power electronics for electric vehicles. SiC and GaN are not just incremental improvements over Si; they represent a fundamental technological evolution that is enabling automakers to build EVs that are more powerful, more efficient, and more sustainable. As costs decline and design expertise matures, the shift from silicon to WBG semiconductors will become not just advantageous—but inevitable.

The success of future electric mobility depends significantly on how swiftly and effectively the industry embraces these technologies. With their unique advantages and growing ecosystem, SiC and GaN will define the future of EV power electronics, pushing the boundaries of performance and redefining what electric vehicles can achieve.

References

[1] Ghazanfari, A., Perreault, C., & Zaghib, K. (2019, June). EV/HEV industry trends of wide-bandgap power semiconductor devices for power electronics converters. In 2019 IEEE 28th International Symposium on Industrial Electronics (ISIE) (pp. 1917-1923). IEEE.
[2] Das, S., Marlino, L. D., & Armstrong, K. O. (2018). Wide bandgap semiconductor opportunities in power electronics (No. ORNL/TM-2017/702). Oak Ridge National Laboratory (ORNL), Oak Ridge, TN (United States).
[3] Warren, J. A., Riddle, M. E., Graziano, D. J., Das, S., Upadhyayula, V. K., Masanet, E., & Cresko, J. (2015). Energy impacts of wide band gap semiconductors in US light-duty electric vehicle fleet. Environmental science & technology, 49(17), 10294-10302.
[4] Do, T. V., Li, K., Trovão, J. P., & Boulon, L. (2020, November). Reviewing of using wide-bandgap power semiconductor devices in electric vehicle systems: From component to system. In 2020 IEEE Vehicle Power and Propulsion Conference (VPPC) (pp. 1-6). IEEE.
[5] Bérubé, Y., Ghazanfari, A., Blanchette, H. F., Perreault, C., & Zaghib, K. (2020, October). Recent advances in wide bandgap devices for automotive industry. In IECON 2020 the 46th annual conference of the ieee industrial electronics society (pp. 2557-2564). IEEE.
[6] Bindra, A., & Keim, T. (2018). Exciting Advances in Power Electronics: APEC 2018 Divulges Latest Advances in Magnetics, Wide-Bandgap Devices, Vehicle Batteries, 3-D Packaging, and More. IEEE Power Electronics Magazine, 5(2), 49-55.
[7] Pinkos, A. F., & Guo, Y. (2013, May). Automotive design challenges for wide-band-gap devices used in high temperature capable, scalable power vehicle electronics. In 2013 IEEE Energytech (pp. 1-5). IEEE.

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[8] Okumura, H. (2015). A roadmap for future wide bandgap semiconductor power electronics. Mrs Bulletin, 40(5), 439-444.
[9] Spaziani, L., & Lu, L. (2018, May). Silicon, GaN and SiC: There's room for all: An application space overview of device considerations. In 2018 IEEE 30th International Symposium on Power Semiconductor Devices and ICs (ISPSD) (pp. 8-11). IEEE.
[10] Su, M., Chen, C., & Rajan, S. (2013). Prospects for the application of GaN power devices in hybrid electric vehicle drive systems. Semiconductor Science and Technology, 28(7), 074012.
[11] Ohashi, H. (2003, October). Power electronics innovation with next generation advanced power devices. In The 25th International Telecommunications Energy Conference, 2003. INTELEC'03. (pp. 9-13). IEEE.
[12] Iacopi, F., Van Hove, M., Charles, M., & Endo, K. (2015). Power electronics with wide bandgap materials: Toward greener, more efficient technologies. Mrs Bulletin, 40(5), 390-395.
[13] OHASHI, H., OMURA, I., MATSUMOTO, S., SATO, Y., TADANO, H., & ISHII, I. (2004). Power electronics innovation with next generation advanced power devices. IEICE Transactions on communications, 87(12), 3422-3429.
[14] Hamada, K. (2010). Present status and future prospects for electronics in electric vehicles/hybrid electric vehicles and expectations for wide-bandgap semiconductor devices. Silicon carbide, 2, 1-19.
[15] Han, D., Li, S., Lee, W., & Sarlioglu, B. (2017, June). Adoption of wide bandgap technology in hybrid/electric vehicles-opportunities and challenges. In 2017 IEEE Transportation Electrification Conference and Expo (ITEC) (pp. 561-566). IEEE.
[16] Wilson, P. R. (2017). Advanced aircraft power electronics systems—The impact of simulation, standards and wide band-gap devices. CES Transactions on Electrical Machines and Systems, 1(1), 72-82.
[17] Tsao, J. Y., Chowdhury, S., Hollis, M. A., Jena, D., Johnson, N. M., Jones, K. A., ... & Simmons, J. A. (2018). Ultrawide-bandgap semiconductors: research opportunities and challenges. Advanced Electronic Materials, 4(1), 1600501.
[18] Morya, A. K., Gardner, M. C., Anvari, B., Liu, L., Yepes, A. G., Doval-Gandoy, J., & Toliyat, H. A. (2019). Wide bandgap devices in AC electric drives: Opportunities and challenges. IEEE Transactions on Transportation Electrification, 5(1), 3-20.
[19] Dargahi, S., & Williamson, S. S. (2010, September). On the suitability of gallium-nitride (GaN) based automotive power electronics. In 2010 IEEE Vehicle Power and Propulsion Conference (pp. 1-6). IEEE.
[20] Liu, G., Li, K., Wang, Y., Luo, H., & Luo, H. (2020). Recent advances and trend of HEV/EV-oriented power semiconductors–an overview. IET Power Electronics, 13(3), 394-404.

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