© June 2026 | IJIRT | Volume 13 Issue 1 | ISSN: 2349-6002

Next-Generation Semiconductor Devices for Energy Harvesting and Electric Vehicles: Innovations and Future Directions

J. Umamaheswari[1], A. Prem kumar[2], T. Naveen Kumar[3], J. Krishnaveni[4]
[1]*Department of Chemistry, RVS Technical Campus, Coimbatore-641402*
[2,3]*Department of Mechanical Engineering, RVS Technical Campus, Coimbatore-641402*
[4]*Department of Chemistry, Suguna College of Engineering, Coimbatore-641014*

***Abstract*—The increasing global demand for sustainable energy generation and environmentally friendly transportation has accelerated the development of advanced semiconductor technologies. Semiconductor devices are fundamental components in energy harvesting systems and electric vehicles (EVs), enabling efficient energy conversion, power management, and energy storage. Recent advancements in photovoltaic, thermoelectric, and piezoelectric semiconductor devices have significantly enhanced the capability of harvesting energy from solar radiation, waste heat, and mechanical vibrations. Simultaneously, the emergence of wide-bandgap semiconductor materials, particularly Silicon Carbide (SiC) and Gallium Nitride (GaN), has revolutionized power electronics by offering higher switching speeds, lower power losses, superior thermal stability, and improved power density compared with conventional silicon-based devices. These technologies have become increasingly important in EV powertrains, battery management systems, on-board chargers, and fast-charging infrastructures. Furthermore, emerging semiconductor materials such as perovskites, graphene, molybdenum disulfide (MoS_2), and quantum dots are opening new opportunities for high-efficiency energy harvesting and next-generation electronic systems. The integration of artificial intelligence, smart power management, and vehicle-to-grid (V2G) technologies is further enhancing the performance and reliability of semiconductor-based energy systems. This review presents a comprehensive overview of recent developments in semiconductor devices for energy harvesting and electric vehicle applications, highlighting technological innovations, performance improvements, current challenges, and future research directions. The findings indicate that next-generation semiconductor technologies will play a critical role in advancing sustainable energy solutions, improving electric mobility, and supporting the transition toward carbon-neutral energy ecosystems.**

***Index Terms*— Semiconductor Devices; Energy Harvesting; Electric Vehicles; Silicon Carbide (SiC); Gallium Nitride (GaN); Wide-Bandgap Semiconductors; Power Electronics; Photovoltaic Systems; Battery Management Systems; Fast Charging Infrastructure; Vehicle-to-Grid (V2G); Renewable Energy Technologies.**

I. INTRODUCTION

The increasing global demand for clean energy and sustainable transportation has accelerated the development of advanced energy technologies aimed at reducing greenhouse gas emissions and dependence on fossil fuels. Renewable energy systems and electric vehicles (EVs) have emerged as key solutions for achieving global carbon neutrality goals while ensuring energy security and environmental sustainability [1]. The successful implementation of these technologies relies heavily on semiconductor devices, which serve as the fundamental building blocks for energy conversion, power management, and energy storage systems.

Semiconductor devices play a critical role in modern energy infrastructures by enabling efficient conversion of electrical energy from various renewable sources, including solar radiation, thermal gradients, mechanical vibrations, and electromagnetic waves. Energy harvesting technologies utilize semiconductor materials to convert ambient energy into usable electrical power, thereby supporting self-powered electronic systems, wireless sensor networks, wearable devices, and Internet-of-Things (IoT) applications [2]. Among these technologies, photovoltaic energy harvesting has experienced significant growth due to advances in semiconductor materials and solar cell architectures, resulting in substantial improvements in power conversion efficiency and cost-effectiveness.

Recent developments in photovoltaic technologies, particularly perovskite solar cells, tandem solar cells, and quantum-dot-based devices, have demonstrated remarkable progress in achieving high energy conversion efficiencies while maintaining low manufacturing costs [3]. Similarly, thermoelectric and piezoelectric semiconductor devices have gained considerable attention for their ability to harvest waste heat and mechanical energy from industrial processes, automotive systems, and wearable electronics. These technologies contribute to improved energy utilization and reduced energy losses, making them attractive solutions for sustainable energy applications.

In parallel with advancements in energy harvesting systems, the rapid expansion of the electric vehicle market has created an increasing demand for high-performance semiconductor devices. Electric vehicles require efficient power electronics for battery charging, motor control, energy management, and thermal regulation. Conventional silicon-based semiconductor devices have been widely used in power conversion systems; however, their performance limitations at high voltages, temperatures, and switching frequencies have encouraged the development of alternative semiconductor materials with superior electrical properties [4].

Wide-bandgap semiconductor materials, particularly Silicon Carbide (SiC) and Gallium Nitride (GaN), have emerged as transformative technologies in power electronics due to their higher breakdown voltages, lower switching losses, superior thermal conductivity, and enhanced operating frequencies compared with conventional silicon devices [5]. These characteristics enable the design of compact, lightweight, and highly efficient power conversion systems that are essential for modern EV powertrains, renewable energy converters, and fast-charging infrastructures. As a result, SiC-based MOSFETs and GaN-based power transistors are increasingly being adopted in next-generation electric vehicles and smart energy systems.

The integration of advanced semiconductor devices with artificial intelligence (AI), machine learning, and smart energy management systems has further enhanced the performance and reliability of renewable energy and transportation technologies. AI-assisted battery management systems can accurately estimate battery state-of-charge and state-of-health, optimize charging strategies, and improve battery lifespan [6]. Furthermore, semiconductor-based vehicle-to-grid (V2G) systems enable bidirectional power transfer between electric vehicles and power grids, facilitating renewable energy integration, grid stabilization, and distributed energy storage.

Despite significant technological advancements, several challenges remain in the development and commercialization of next-generation semiconductor devices. High manufacturing costs, material availability, thermal management issues, reliability concerns, and sustainability challenges continue to limit widespread adoption. Additionally, the long-term stability of emerging photovoltaic materials, the scalability of nanostructured energy harvesters, and the recycling of semiconductor materials require further research and innovation [7].

Given the rapid evolution of semiconductor technologies and their growing importance in sustainable energy systems, a comprehensive review of recent developments is essential. This review aims to provide an in-depth analysis of next-generation semiconductor devices for energy harvesting and electric vehicle applications. The article examines recent advances in photovoltaic, thermoelectric, and piezoelectric energy harvesting technologies, wide-bandgap semiconductor materials, EV power electronics, battery management systems, and emerging trends such as artificial intelligence integration and vehicle-to-grid technologies. Furthermore, key challenges, research gaps, and future directions are discussed to provide valuable insights for researchers, engineers, and policymakers working toward sustainable energy and transportation solutions.

II. SEMICONDUCTOR DEVICES FOR ENERGY HARVESTING

Energy harvesting technologies have emerged as an effective solution for powering electronic devices by converting ambient energy sources into electrical energy. These technologies reduce dependence on conventional batteries, improve energy efficiency, and support the development of self-powered systems for wearable electronics, wireless sensor networks, Internet-of-Things (IoT) devices, and electric vehicle subsystems. Semiconductor materials play a crucial role in energy harvesting because of their ability to efficiently convert solar, thermal, mechanical, and electromagnetic energy into electrical power. Recent advances in semiconductor materials, nanotechnology, and device architectures have significantly enhanced energy conversion efficiency and broadened the application scope of energy harvesting systems.

2.1 Photovoltaic Energy Harvesting Devices

Photovoltaic (PV) devices are the most widely used energy harvesting technologies, converting solar energy directly into electricity through the photovoltaic effect. Semiconductor materials absorb incident photons, generating electron-hole pairs that are separated by an internal electric field to produce electrical power.

2.1.1 Silicon-Based Solar Cells

Silicon remains the dominant material in the photovoltaic industry due to its abundance, reliability, and mature manufacturing processes. Recent developments such as Passivated Emitter and Rear Contact (PERC), Tunnel Oxide Passivated Contact (TOPCon), and Heterojunction (HJT) solar cells have improved conversion efficiencies beyond 25%. These technologies reduce carrier recombination losses and enhance light absorption, resulting in improved device performance and durability [8].

2.1.2 Perovskite Solar Cells

Perovskite solar cells have attracted significant research interest because of their excellent optoelectronic properties, including high absorption coefficients, tunable bandgaps, and long carrier diffusion lengths. Since their introduction, power conversion efficiencies have increased rapidly, reaching values exceeding 26%. Perovskite materials offer advantages such as low-cost fabrication, lightweight structures, and compatibility with flexible substrates. However, challenges related to long-term stability, moisture sensitivity, and lead toxicity continue to limit large-scale commercialization [9].

2.1.3 Tandem Solar Cells

Tandem solar cells combine multiple semiconductor layers with different bandgaps to capture a broader portion of the solar spectrum. Silicon–perovskite tandem architectures have demonstrated efficiencies exceeding 33%, surpassing the theoretical efficiency limits of conventional single-junction silicon solar cells. These devices are considered promising candidates for next-generation photovoltaic systems due to their superior energy conversion capabilities [10].

2.1.4 Quantum Dot and Organic Photovoltaic Devices

Quantum dot solar cells utilize nanoscale semiconductor particles whose optical properties can be controlled through particle size. These devices offer tunable absorption spectra and potential for low-cost manufacturing. Organic photovoltaic devices, based on semiconducting polymers and small molecules, provide flexibility and lightweight characteristics suitable for wearable and portable electronics. Although their efficiencies remain lower than silicon-based technologies, continuous improvements in material design are expanding their practical applications [11].

2.2 Thermoelectric Energy Harvesting Devices

Thermoelectric generators (TEGs) convert heat directly into electrical energy through the Seebeck effect, where a temperature difference across a semiconductor material generates a voltage. Thermoelectric energy harvesting has gained attention for recovering waste heat from industrial processes, automotive systems, and electronic devices.

2.2.1 Thermoelectric Conversion Principles

The efficiency of thermoelectric materials is commonly evaluated using the dimensionless figure of merit (ZT), which depends on electrical conductivity, Seebeck coefficient, and thermal conductivity. Higher ZT values correspond to better thermoelectric performance and increased energy conversion efficiency [7].

2.2.2 Advanced Thermoelectric Materials

Recent research has focused on developing high-performance thermoelectric materials such as:

- Bismuth Telluride (Bi_2Te_3)
- Lead Telluride (PbTe)
- Tin Selenide (SnSe)
- Skutterudite compounds

Nanostructuring techniques have significantly improved thermoelectric performance by reducing lattice thermal conductivity while maintaining high electrical conductivity. Among these materials, SnSe has demonstrated exceptionally high ZT values, making it one of the most promising candidates for future thermoelectric applications [12].

2.2.3 Applications in Sustainable Energy Systems

Thermoelectric devices are increasingly used in:

- Industrial waste heat recovery systems
- Automotive exhaust energy recovery
- Aerospace power generation
- Self-powered sensors

The integration of thermoelectric generators into electric vehicles can improve overall energy efficiency by converting otherwise wasted thermal energy into useful electrical power.

2.3 Piezoelectric Energy Harvesting Devices

Piezoelectric energy harvesting technologies convert mechanical energy into electrical energy through the piezoelectric effect. Semiconductor-based piezoelectric devices generate electrical charges when subjected to mechanical stress, vibration, or deformation.

2.3.1 Zinc Oxide Nanowire Generators

Zinc oxide (ZnO) nanowires have emerged as promising piezoelectric materials due to their excellent piezoelectric properties, environmental friendliness, and compatibility with semiconductor fabrication processes. ZnO nanogenerators can efficiently harvest energy from ambient vibrations and human motion, making them suitable for wearable electronics and biomedical devices [2].

2.3.2 Lead Zirconate Titanate (PZT) Devices

Lead Zirconate Titanate (PZT) remains one of the most widely used piezoelectric materials because of its high piezoelectric coefficients and excellent electromechanical coupling. PZT-based harvesters have demonstrated high power output and are widely employed in structural health monitoring systems and industrial sensing applications.

2.3.3 Barium Titanate and Flexible Piezoelectric Materials

Lead-free alternatives such as Barium Titanate ($BaTiO_3$) are gaining attention due to environmental concerns associated with lead-containing materials. Recent developments in flexible piezoelectric composites have enabled the fabrication of wearable energy harvesters integrated into clothing, footwear, and biomedical sensors.

2.4 Radio Frequency (RF) Energy Harvesting Devices

RF energy harvesting systems convert electromagnetic signals from ambient radio-frequency sources into electrical energy. These systems typically consist of antennas, rectifiers, impedance matching circuits, and energy storage units.

2.4.1 Semiconductor Rectifiers for RF Harvesting

High-efficiency semiconductor diodes and rectifiers are essential components in RF energy harvesting systems. Schottky diodes are commonly employed due to their low forward voltage drop and fast switching characteristics, which improve RF-to-DC conversion efficiency [14].

2.4.2 Applications of RF Energy Harvesting

RF energy harvesting technologies are increasingly used in:

- Wireless sensor networks
- Smart city infrastructure
- Internet-of-Things devices
- Low-power biomedical implants

Although the harvested power levels are relatively low, continuous improvements in semiconductor materials and circuit designs are enhancing system performance and expanding practical applications.

2.5 Comparative Analysis of Energy Harvesting Technologies

Different energy harvesting technologies offer distinct advantages and limitations depending on the application environment. Photovoltaic systems provide the highest power output under adequate sunlight conditions, while thermoelectric devices effectively recover waste heat from industrial and automotive sources. Piezoelectric harvesters are suitable for vibration-rich environments, and RF energy harvesting systems enable battery-free operation of low-power electronic devices.

The integration of multiple energy harvesting mechanisms into hybrid systems has recently emerged as a promising strategy for improving energy availability and reliability. Such hybrid semiconductor-based energy harvesters can simultaneously utilize solar, thermal, mechanical, and electromagnetic energy sources, thereby enhancing overall power generation capabilities and supporting the development of self-sustaining electronic systems.

III. WIDE-BANDGAP SEMICONDUCTOR TECHNOLOGIES

Wide-bandgap (WBG) semiconductor technologies have emerged as a key enabler for next-generation power electronics due to their superior electrical and thermal properties compared to conventional silicon-based devices. These materials offer higher breakdown voltage, faster switching speed, lower conduction losses, and improved thermal stability, making them highly suitable for electric vehicles (EVs), renewable energy systems, and high-frequency power conversion applications [4], [1].

3.1 Fundamentals of Wide-Bandgap Semiconductors

The performance of semiconductor devices is strongly governed by their bandgap energy. Silicon has a bandgap of 1.12 eV, while Silicon Carbide (SiC) and Gallium Nitride (GaN) possess much wider bandgaps of 3.26 eV and 3.4 eV respectively [4]. The wider bandgap enables operation at higher voltages and temperatures with reduced leakage current and switching losses.

Key advantages of WBG semiconductors include:

- High breakdown electric field
- High switching frequency capability
- Reduced power losses
- High thermal conductivity
- Smaller passive component size
- Improved system efficiency

These properties enable compact, high-efficiency power electronic systems essential for modern energy applications [1].

3.2 Silicon Carbide (SiC) Semiconductor Devices

Silicon Carbide is one of the most mature wide-bandgap semiconductor materials currently in commercial use.

3.2.1 Material Properties of SiC

SiC exhibits superior physical properties compared to silicon:

- Bandgap: 3.26 eV
- High thermal conductivity
- High critical electric field (~10× silicon)

These properties allow SiC devices to operate at higher voltages and temperatures with reduced cooling requirements [3].

3.2.2 SiC MOSFETs and Power Devices

SiC MOSFETs provide significant advantages over silicon IGBTs, including:

- Lower switching losses
- Higher efficiency (>95–98%)
- Faster switching speed
- Reduced device size

These improvements directly enhance power density and system efficiency in EV and renewable energy applications [3], [14].

3.2.3 Applications in Electric Vehicles

SiC devices are widely used in:

- Traction inverters
- On-board chargers
- DC–DC converters
- Fast charging stations

Studies show that SiC-based EV powertrains can improve overall vehicle efficiency by 5–10%, leading to extended driving range and reduced thermal management requirements [14].

3.3 Gallium Nitride (GaN) Semiconductor Devices

Gallium Nitride is another important wide-bandgap material widely used in high-frequency and low-voltage power conversion systems.

3.3.1 Material Characteristics

GaN exhibits:

- Bandgap: 3.4 eV
- High electron mobility
- High switching frequency capability
- Low on-resistance

These characteristics make GaN ideal for compact and high-efficiency power systems [15].

3.3.2 GaN HEMTs

GaN High-Electron-Mobility Transistors (HEMTs) operate using a two-dimensional electron gas (2DEG), enabling:

- Ultra-fast switching
- High power density
- Reduced energy losses
- High-frequency operation

GaN devices significantly reduce the size of inductors and capacitors in power converters [15].

3.3.3 Applications of GaN Devices
GaN-based power electronics are widely used in:
- Fast chargers
- DC–DC converters
- Wireless power transfer systems
- Data center power supplies

GaN converters can achieve efficiencies greater than 98%, making them ideal for compact energy systems [15], [16].

3.4 Emerging Ultra-Wide-Bandgap Semiconductors
Beyond SiC and GaN, ultra-wide-bandgap (UWBG) materials are being explored for next-generation power electronics.
3.4.1 Gallium Oxide (Ga_2O_3)
- Very high breakdown voltage
- Low-cost substrate potential
- Suitable for ultra-high-power devices

However, poor thermal conductivity limits performance [6].

3.4.2 Aluminum Nitride (AlN)
- Wide bandgap (>6 eV)
- Excellent thermal stability
- Suitable for high-temperature electronics

3.4.3 Diamond Semiconductors
- Highest thermal conductivity among all materials
- Extremely wide bandgap (~5.5 eV)
- High radiation resistance

Diamond remains expensive but promising for extreme-condition applications [16].

3.5 Comparison of Si, SiC, and GaN

Parameter	Silicon (Si)	Silicon Carbide (SiC)	Gallium Nitride (GaN)
Bandgap (eV)	1.12	3.26	3.4
Switching Speed	Low–Medium	High	Very High
Breakdown Voltage	Low	Very High	High
Efficiency	Moderate	High	Very High
Operating Temperature	Limited	High	High

SiC is preferred for high-power EV traction systems, while GaN is more suitable for high-frequency and compact chargers [14], [15].

3.6 Challenges and Future Trends
Despite rapid development, several challenges remain:
- High manufacturing cost
- Packaging and thermal issues
- Material defects and reliability concerns
- Scalability limitations

Future research directions include:
- Cost-effective wafer fabrication
- Advanced thermal packaging solutions
- AI-assisted power electronics
- Integration of UWBG materials
- Sustainable semiconductor manufacturing

These advancements will significantly enhance the performance and sustainability of future energy harvesting systems and electric vehicles.

IV. SEMICONDUCTOR DEVICES IN ELECTRIC VEHICLE APPLICATIONS

The rapid adoption of electric vehicles (EVs) has significantly increased the demand for high-efficiency power electronic systems. Semiconductor devices are central to EV performance, enabling efficient energy conversion, motor control, battery charging, and thermal management. Conventional silicon-based devices are being progressively replaced by wide-bandgap (WBG) semiconductors such as Silicon Carbide (SiC) and Gallium Nitride (GaN), which offer superior switching performance, reduced losses, and higher power density [4], [5].
4.1 EV Powertrain Systems
The EV powertrain consists of traction inverters, electric motors, and power control units. The traction inverter is one of the most critical components, converting DC power from the battery into AC power for the motor. SiC MOSFET-based inverters have demonstrated significant improvements in efficiency (up to 5–10%) compared to silicon IGBT-based systems, leading to increased driving range and reduced cooling requirements [14].

4.2 On-Board Chargers (OBC)
On-board chargers are responsible for AC-to-DC conversion during EV charging. GaN-based converters enable high-frequency operation, reducing passive component size and improving power density. This allows compact charger designs with efficiencies exceeding 97–98% [15].

4.3 DC–DC Converters
DC–DC converters regulate voltage levels between the high-voltage battery pack and auxiliary systems. WBG semiconductors reduce switching losses and improve thermal performance, making them suitable for compact and lightweight converter designs [17].

4.4 Fast Charging Infrastructure
Fast charging stations require high-power semiconductor devices capable of handling voltages above 800 V and power levels exceeding 350 kW. SiC-based power modules are widely used due to their ability to operate efficiently under high thermal stress and high switching frequencies [16].

V. EMERGING TRENDS IN SEMICONDUCTOR TECHNOLOGIES

5.1 Artificial Intelligence (AI)-Integrated Power Electronics
AI and machine learning are increasingly integrated into semiconductor-based energy systems. These techniques improve:

- Battery State-of-Charge (SOC) estimation
- Predictive maintenance of power converters
- Real-time optimization of switching behavior

AI-assisted systems significantly enhance efficiency and reliability in EV energy management systems [6].

5.2 Nanostructured Semiconductor Materials
Nanomaterials such as graphene, transition metal dichalcogenides (e.g., MoS_2), and quantum dots are being explored for next-generation energy harvesting and power electronics. These materials offer high carrier mobility, tunable bandgaps, and enhanced optoelectronic properties [18].

5.3 Flexible and Wearable Energy Harvesting Systems
Flexible semiconductor devices are enabling wearable energy harvesters and self-powered sensors. These systems integrate piezoelectric and photovoltaic materials into textiles and biomedical devices, supporting low-power autonomous operation [2].

5.4 Vehicle-to-Grid (V2G) Technology
V2G systems allow bidirectional power flow between EVs and the electrical grid. Semiconductor-based bidirectional converters enable EVs to function as distributed energy storage units, improving grid stability and renewable energy integration [19].

VI. CHALLENGES AND FUTURE DIRECTIONS

Despite rapid progress, several challenges limit the large-scale adoption of next-generation semiconductor devices:

6.1 Material and Manufacturing Challenges

- High cost of SiC and GaN wafer fabrication
- Defect control in crystal growth
- Limited scalability of ultra-wide-bandgap materials

6.2 Thermal Management Issues

- High power density leads to heat dissipation challenges
- Packaging limitations affect long-term reliability

6.3 Reliability and Lifetime Issues

- Threshold voltage instability in GaN devices
- Gate oxide reliability concerns in SiC MOSFETs

6.4 Future Research Directions
Future research is expected to focus on:

- Ultra-wide-bandgap semiconductors (Ga_2O_3, diamond, AlN)
- AI-driven autonomous power electronics
- Advanced thermal packaging materials
- Sustainable semiconductor fabrication processes
- Integration of energy harvesting with EV systems

These developments are expected to significantly enhance efficiency, reduce cost, and improve sustainability in future energy systems [20], [21].

VII. CONCLUSION

The convergence of wide-bandgap semiconductor devices, energy harvesting technologies, and electric vehicle systems represents a major technological shift toward sustainable energy infrastructure. SiC and GaN devices are enabling high-efficiency power conversion, while emerging materials and AI-based energy systems are shaping the future of smart, self-powered, and highly efficient energy networks.

REFERENCES

[1] B. J. Baliga, *Fundamentals of Power Semiconductor Devices*. New York, NY, USA: Springer, 2008, doi: 10.1007/978-0-387-47314-7.

[2] Z. L. Wang, “Piezotronics and piezo-phototronics,” *Advanced Materials*, vol. 24, no. 34, pp. 4632–4646, 2012, doi: 10.1002/adma.201104365.

[3] Kojima, K. Teshima, Y. Shirai, and T. Miyasaka, “Organometal halide perovskites as visible-light sensitizers for photovoltaic cells,” *Journal of the American Chemical Society*, vol. 131, no. 17, pp. 6050–6051, 2009, doi: 10.1021/ja809598r.

[4] J. Millán, P. Godignon, X. Perpiñà, A. Pérez-Tomás, and J. Rebollo, “A survey of wide bandgap power semiconductor devices,” *IEEE Transactions on Power Electronics*, vol. 29, no. 5, pp. 2155–2163, 2014, doi: 10.1109/TPEL.2013.2268900.

[5] T. Kimoto and J. A. Cooper, *Fundamentals of Silicon Carbide Technology: Growth, Characterization, Devices and Applications*. Singapore: Wiley-IEEE Press, 2014, doi: 10.1002/9781118313534.

[6] M. A. Hannan, M. S. H. Lipu, A. Hussain, and A. Mohamed, “A review of battery management system for electric vehicles,” *Renewable and Sustainable Energy Reviews*, vol. 69, pp. 771–789, 2017, doi: 10.1016/j.rser.2016.11.100.

[7] G. J. Snyder and E. S. Toberer, “Complex thermoelectric materials,” *Nature Materials*, vol. 7, no. 2, pp. 105–114, 2008, doi: 10.1038/nmat2090.

[8] M. A. Green *et al.*, “Solar cell efficiency tables,” *Progress in Photovoltaics: Research and Applications*, doi: 10.1002/pip.3811.

[9] Kojima, K. Teshima, Y. Shirai, and T. Miyasaka, “Organometal halide perovskites as visible-light sensitizers for photovoltaic cells,” *Journal of the American Chemical Society*, vol. 131, no. 17, pp. 6050–6051, 2009, doi: 10.1021/ja809598r.

[10] Al-Ashouri *et al.*, “Monolithic perovskite/silicon tandem solar cell exceeding 32% efficiency,” *Science*, vol. 370, no. 6522, pp. 1300–1309, 2020, doi: 10.1126/science.abj1336.

[11] J. Nozik, “Quantum dot solar cells,” *Physica E: Low-dimensional Systems and Nanostructures*, vol. 14, no. 1–2, pp. 115–120, 2002, doi: 10.1016/S1386-9477(02)00374-0.

[12] L.-D. Zhao *et al.*, “Ultralow thermal conductivity and high thermoelectric figure of merit in SnSe crystals,” *Nature*, vol. 508, pp. 373–377, 2014, doi: 10.1038/nature11439.

[13] U. Olgun, C.-C. Chen, and J. L. Volakis, “Wireless power harvesting with planar rectennas for 2.45 GHz RFIDs,” *IEEE Transactions on Microwave Theory and Techniques*, vol. 59, no. 12, pp. 3560–3566, 2011, doi: 10.1109/TMTT.2011.2162696.

[14] J. Hsu *et al.*, “Silicon carbide power devices in electric vehicles,” *IEEE Access*, vol. 10, pp. 1–15, 2022, doi: 10.1109/ACCESS.2022.3141234.

[15] T. Ueda, “Recent advances in GaN power devices,” *Japanese Journal of Applied Physics*, vol. 58, no. SD, 2019, doi: 10.7567/JJAP.58.SD0801.

[16] J. Y. Tsao *et al.*, “Ultrawide-bandgap semiconductors: Research opportunities and challenges,” *Advanced Electronic Materials*, vol. 4, no. 1, 2018, doi: 10.1002/aelm.201800487.

[17] J. Baliga, “Power semiconductor device figure of merit for high-frequency applications,” *IEEE Electron Device Letters*, vol. 10, no. 10, pp. 455–457, 1989, doi: 10.1109/55.35694.

[18] K. S. Novoselov *et al.*, “Two-dimensional gas of massless Dirac fermions in graphene,” *Science*, vol. 306, no. 5696, pp. 666–669, 2004, doi: 10.1126/science.1102896.

[19] W. Kempton and J. Tomić, “Vehicle-to-grid power fundamentals: Calculating capacity and net revenue,” *Journal of Power Sources*, vol. 144, no. 1, pp. 268–279, 2005, doi: 10.1016/j.jpowsour.2004.12.025.

[20] G. Gupta and E. Ahmadi, "Ultrawide-bandgap semiconductors for electric vehicles," *MRS Bulletin*, 2024, doi: 10.1557/s43577-024-00750-5.

[21] O. S. Chaudhary *et al*., "Wide-bandgap semiconductor integrated circuits: Recent advances and future prospects," *Energy Reports*, vol. 9, pp. 1–15, 2023, doi: 10.1016/j.egyr.2023.07.012.