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Review Article

Review and Evaluation of Power Devices and Semiconductor Materials Based on Si, SiC, and Ga-N

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There is no reservation that semiconductor equipment distorted the world despite the fact of doing the practical experiments and also in research field. Researchers will communicate the process of semiconductor statistics with nearby pupils. In this work, diverse brand of semiconductor equipment was thrashed out with elementary properties and their distinctiveness. One type of semiconductor is differentiated based on energy band gap with an added type of semiconductor equipment. Semiconductor resources are the edifice block for the electrical and electronics component. This work makes an available apt generic argument of materials with the latest discussion and its impact of temperature on different materials, and it also reveals dissimilar parameters such as modern density, porch voltage value, transmission rate, and drain resistance value. Exceptional applications were discussed for divergent semiconductor materials.

1. Introduction

In modern narration, assorted semiconductor equipment was completed with a mixture of semiconductor characteristics. A semiconductor is equipment having a conductivity array vary from one process to another process. It reveals an assortment of concert factors, and it will be discussed in the following section. It has classical band gap energy level assortment from 1 to 5 eV, while an insulator has superior crowd gap when evaluating other semiconductor equipment [1, 2]. The semiconductor equipment is accessible at room temperature more or less at 300 K and is mulled over to be smaller energy across the band gap. The equipment has the capability to organize the indicted carriers at the furthermost technology importance. Semiconductor equipment is very responsive to the impurity according to the precious stone lattice, and the different numbers of charge carries are at hand. It crashed on two sundry semiconductor equipment such as intrinsic and extrinsic; the resources which perform activist type of semiconductor are enabled as intrinsic, and those which result in the dopant part are enabled as extrinsic. Organic semiconductor is executed as an electrochemical scheme for various electrical and electronic devices. For example, liquid-crystal display, light-emitting diode, and sensor equip the semiconductor devices that facilitate electrical and mechanical properties [3, 4]. The greatest benefit of using semiconductor equipment in a converter and an inverter is that it gives the best outcome in the output part of the system. But the major downside is that the semiconductor materials give the unfortunate performance in mechanical parts. Moreover, the crude parts are composed of thin film schemes because it performs with subordinate crack resistance value than the bulk material parts. Semiconductor equipment is performed with tensile potency properties, and it is determined by linear slope curve [1, 2]. The electrical conductivity of the semiconductor equipment increases with high temperature, with the strength of the metal. Mainly, the semiconductor occurs in electrons and holes, and it is known as charge carriers. When the schemes are doped with hole, it is concerned with p type and with free electron it is known as n type. Most of the semiconductor materials are composed of germanium and silicon. There is also enhancement in semiconductor materials by expending Sic and amalgamation of Ga-N HEMT structure; lastly, it resulted with high-temperature, wild swapping rate devices. The operation of using the Ga-N HEMT resources in exchanging devices has high energy efficiency. Developing a new material demonstrates well-developed performance in invention generation [5].

Division I performs the introduction of the work. Section 2 states the classification of switching families. Section 3 states the materials used in semiconductor devices. Section 4 imitates the topology of switching devices. Section 5 discusses the performance analysis of switching families. Section 6 initiates the comparison of switching device families. Section 7 inhibits with the comparison of Si-C, Si, and Ga-N semiconductor materials. Finally, conclusion is discussed in Section 8

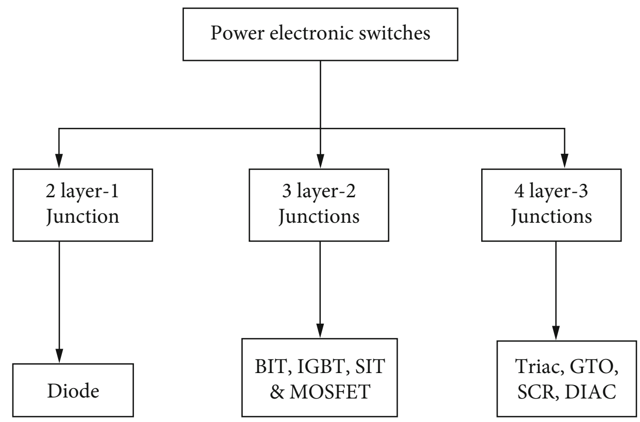

Figure 1: Structural plan of power switching families.

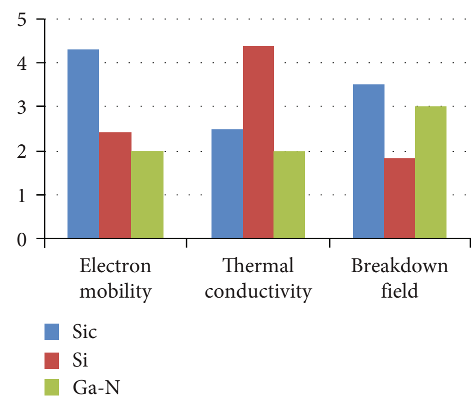

Figure 2: Structural diagram for Si, Sic, and Ga-N materials.

2. Classification of Switching Families

Power electronics families are mainly classified into 2 terminal and 3 terminal devices. The two terminal devices depend on the circuits which are externally allied to the terminal layers. The three terminal devices do not depend on the exterior circuit in which they are allied but depends on the gating signal. [6, 7] Based on the division, there are three performance families such as 1 junction or 2 layers, 2 junction or 3 layers, and 3 junction or 4 layers. Figure 1 shows the structural plan of power switching families.

3. Materials in Semiconductor Devices

Divergent materials are casted off in semiconductor policies such as SCR, MOSFTET, IGBT, TRIAC, DIAC, GTO, and SITH as shown in the Figure 2. With the addition of more materials and switching devices, the performance analysis is now going to take place. The silicon power devices are not recycled over 150 degrees Celsius since power defeat upsurges in escape current due to extraordinary hotness condition. Therefore, by linking SiC [5, 8, 9] with Ga-N, Ga-N worked with upright temperature condition due to sophisticated band gap. For little power solicitations only SiC prefer, it results in squat glassy voltage. For intermediate and in elevation power applications, IGBT devices favor Ga-N materials. While using Ga-N materials in power devices, the switching harm will result in low case and control in advanced switching frequency. Ga-N results in developed updraft conductivity and extensive band gap length. Based on Ga-N influence, converters result in upper efficiency [10, 11]. This sensible device is widely vacant in market area due to the great stipulations and good necessities. In addition to this, researchers ripen many performance analysis by using Ga-N devices in modelling techniques and electromechanical regions. In magnetic current, high electron mobility makes respectable effort in Ga-N devices, and it is achieved in high energy device applications. It is presently marketed in photonics sensor, and it is topmost scoring device for investigation field. The Ga-N product has a breakdown voltage of 9.7 kV in the forward voltage region. It is easily handy in a wider market area with the output voltage range of 600 V-1.2 kV and converter area operates in 600-3.3 kV. There are so many assistances while using these devices, and it provides a good efficiency in inverters and rectifier area. Additionally, Ga-N-based HEMT structure is fashioned with good results and it is chosen for a wider purpose [12, 13]. HEMT structures amended in dielectric constant and surge breakdown voltage density. By combining Ga-N [9, 14] and HEMT, the breakdown voltage results in 20-600 V, with an outer impedance value range from 40 V to 200 V. On-state resistance value reaches it 24 milliohm.

Table 1: Comparative performance for the Si, SiC, and Ga-N materials.

Parameters	SiC	Si	Ga-N
Electron mobility	650 cm^2/V	1200 cm^2/V	2000 cm^2/V
Thermal conductivity	5 W/cmK	1.5 W/cmK	1.3 W/cmK
Breakdown field	3.5 mV/cm	0.3 mV/cm	3.3 mV/cm

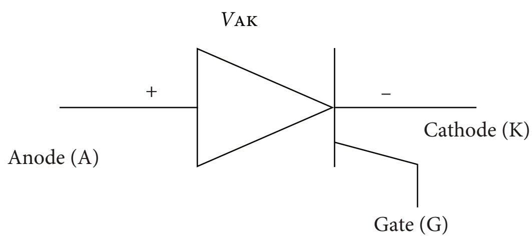

Figure 3: Structural pin of SCR.

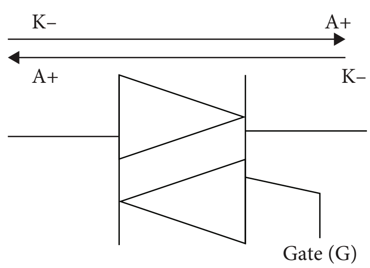

Figure 4: Structural plan of TRIAC.

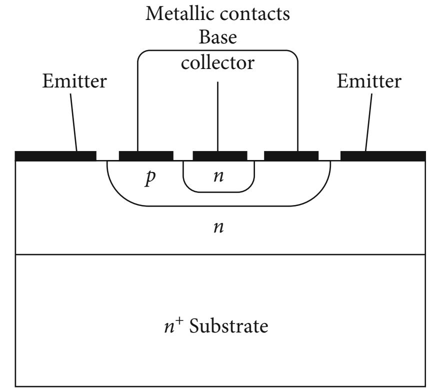

Figure 5: Structural pin of BJT.

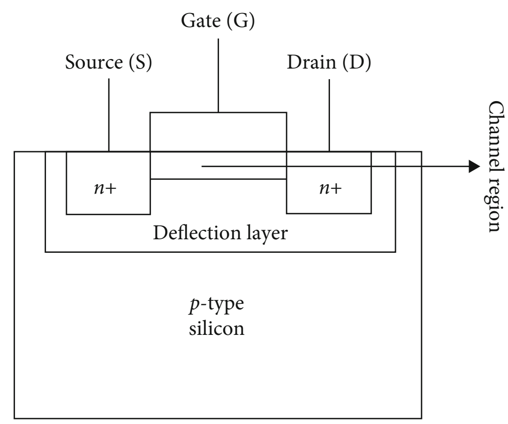

Figure 6: Structural figure of P-type MOSFET.

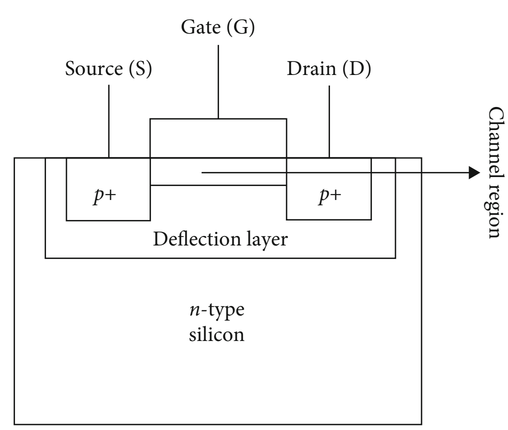

Figure 7: Structural figure of N channel MOSFET.

Now, the comparison takes place between silicon, silicon carbide, and gallium nitride. Table 1 illustrates the comparative performance for the material devices. From the table, Ga-N gives the best outgoing results for the semiconductor switching devices. Figure 1 plans the structural outcome for Si, Si-C, and Ga-N materials.

4. Topology of Switching Devices

4.1. Silicon-Controlled Rectifier. It is a toggle device which connects triple layer mortal anode, cathode, and gate. But the foremost motive is it will accomplish current amid anode and cathode if fitting gate current surged through anode. SCR toggle demeanor is in an onward position when a signal is connected to gate bias. Under static stipulation, the toggle cannot be connecting to the model because the forward current goes to zero position. To act upon the output voltage elevated, the triggering device of gate signal should vary in high position [15].

The silicon-controlled device can be placed in transformer primary winding; the use of inductance spot will get superior which limits the vibrant response of the system. Additionally, this toggle device performs back to back position in which the knob sets in activist and depressing cycle and it produces an AC output waveforms [7]. Using SCR is very efficient and has sturdy control, and the response is very elevated while using this toggle device. Figure 3 indicates the structural pin of SCR [16]. This device is used for inverter charging position for electric passenger vehicles. It is equipped with inverter commutation module of ac/dc techniques at rated values [4, 17]. Therefore, a charger permits electrical isolation between the vehicle transmission systems to charge the efficiency of the structure at the rated

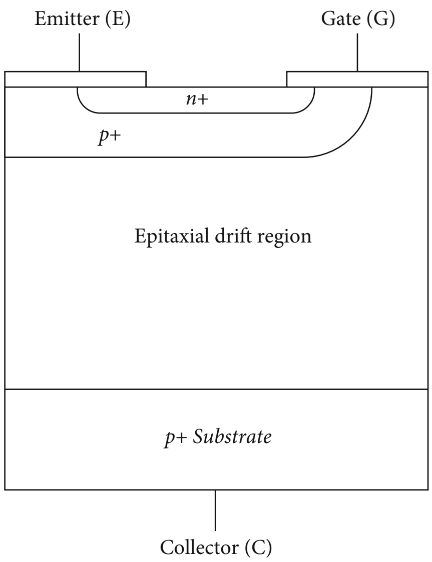

Figure 8: Structural figure of NPT-IGBT.

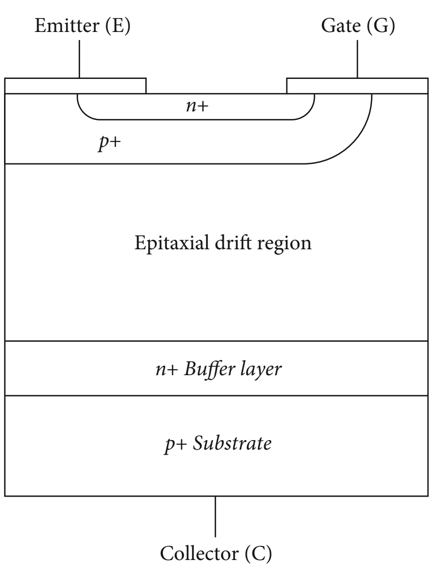

Figure 9: Structural figure of PT-IGBT.

value and also to increase the power factor. The typical value of gate noticed as 1.5 V and 30 mA.

4.2. TRIAC. Figure 4 performs the structural pin of TRIAC. It is famed as triode AC switch, and it is prevalently known as TRIAC. It is avowed as two SCR gates are prohibited from the gate path and the other one is forbidden from the source side [18]. The TRIAC switch is very reasonable, and it is a current sensitivity device, and it has a longer twist rotten time to off the device due to the marginal charge layers. The frequency company of TRIAC is the same as that of SCR; the range is 50-60 Hz. It is used in light dimming control, heating control, and home appliances.

4.3. Bipolar Junction Transistor (BJT). A BJT is an electronic toggle device, and it is used in radio spreader, television,

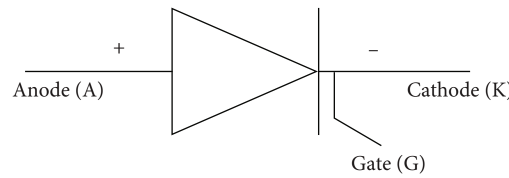

Figure 10: Structural pin of SITH.

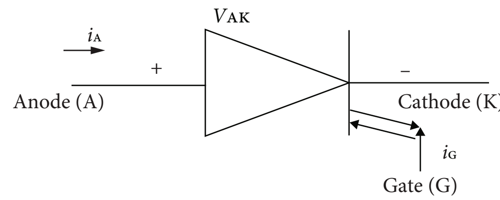

Figure 11: Structural pin of GTO.

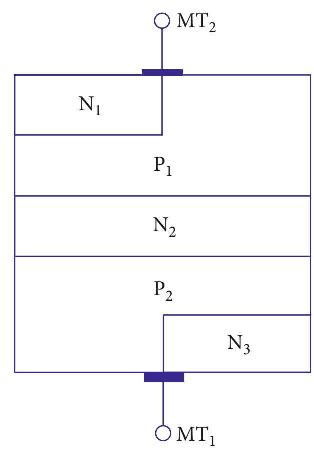

Figure 12: Structural pin of DIAC.

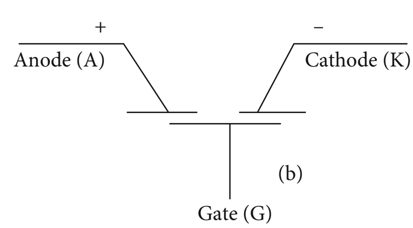

Figure 13: Structural pin of MCT.

desktop, computer, etc. Figure 5 mentions the structural pin of BJT [6, 19]. It has two processes: NPN and PNP. In NPN, both ends are sealed with *n* type semiconductor but in PNP middle layer alone allied with semiconductor material [20, 21]. When NPN BJT process takes place, there is a current stream through the outer source, viz, battery; therefore, electrons from the base *p* type semiconductor stuff to the emitter region are made up of *n* type semiconductor substance. The electrons tour from the base to the *p* type semiconductor material and then set out to the emitter or collector region to the *n* type semiconductor cloth. The layer

Table 2: Performance analysis of switching analysis of SCR, MOSFET, IGBT, BJT, DIAC, TRIAC, and SITH.

S. no.	Parameters	SCR	BJT	MOSFET	IGBT	TRIAC	DIAC	SITH
1	Operating frequency	400 to 500 Hz	10KHz	100 kHz	10 kHz	50 to 500 Hz	—	—
2	On state voltage drop	2 volts	2 volts	4-5 volts	3 volts	1 to 2 volts	3 volts	1 to 3 volts
3	Maximum voltage current rating	10 kV/5000 A	2 kV/1000 A	600 V/200 A	1500 V/400 A	500 V/25 A	—	—

of *p* type region forms the base and it is squeezed in between the emitter and collector.

The forward bias crossways the base emitter area causing electrons to gush from the emitter to the base and holes from the base to the emitter. The emitter is greatly doped than the base; therefore, the majority of charge carrier currents are electrons from the emitter to the base.

4.4. Metal Oxide Semiconductor Field Effect Transistors (MOSFET). It is famed as a unipolar device because it has one type of transporter terminal, the current flood through the tool is controlled by the voltage regulator, and it has three coating drains, source, and gate. But the gate is wad from the channel film by means of SiO_2. Figure 6 performs the structural pin of *P* channel MOSFET. Figure 7 performs the structural pin of *N* channel MOSFET [7, 22]. It is padding as *p*-layer and *n*-layer augmentation device. The makeup of the depletion MOSFET is the same as that of augmentation MOSFET, but there is a slender channel layer between the source and drain [3, 17]. When *N* channel MOSFET is found operating, the gate voltage boost and the *n* channel becomes fed down due to diminution of electrons and the current becomes zero. When there is positive voltage functional to gate, the electron layer is magnetized more and this conduit starts increasing [15].

4.5. Insulated Gate Bipolar Transistor (IGBT). Figure 8 performs the structural pin of NPT-IGBT. Figure 9 performs the structural pin of PT-IGBT.

The IGBT combines plus from MOSFET and BJT; the MOSFET is proscribed by voltage toggle [23]. The BJT has three coat gates, emitter, and collector. It has no input current, and this device is fully prohibited by voltage regulator device, and it is an earlier operating device.

When IGBT operation takes position, a parasitic element occurs and it does not concern the other components until the switch is turned on. The parasitic components always spin on, and it is termed as latch provision. There are two types of IGBT: symmetric and asymmetric. In symmetric IGBT, there is a flippantly doped N-drift region; consequently, electric field does not arise in the symmetric operation. But when the field layer comes to asymmetric, it is discontinued and the electric field layer gets wider when compared to the symmetric region [24, 25]. It used PT-IGBT and NPT-IGBT. PT-IGBT is well developed in DC circuits while NPT-IGBT occurs in AC circuits, whereas NPT-IGBT is suited for parallel operating device and nearby PT-IGBT has towering optimistic temperature coefficient and soaring operating speed device with a reduction of energy expenditure. NPT-IGBT is constructed from less posh process.

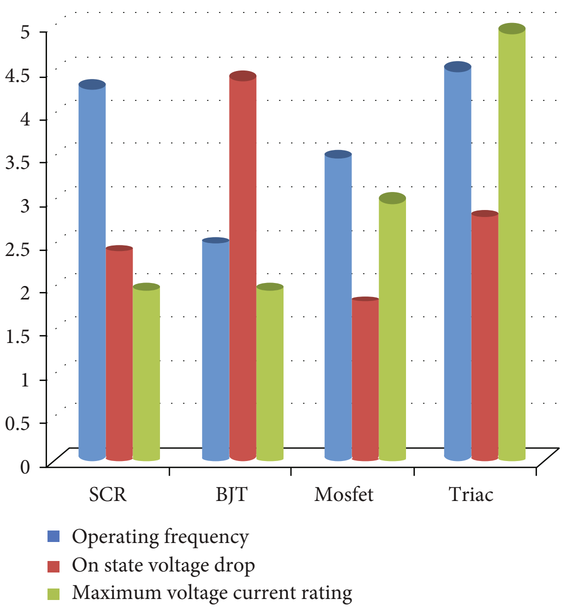

Figure 14: Structural plan diagram for switching device family.

4.6. Static Induction Transistor (SIT). It has the lead from the field effect transistor, and it occurs in elevated breakdown voltage between the gate and drain, but it is maneuvered in high current and voltage [16, 26, 27]. Figure 10 performs the structural pin of SITH. It has a lofty frequency range and elevated volume, and it is used in induction heating element, squat current soaring voltage power tackle, and FM/AM transmitter techniques.

4.7. Gate Turn-Off Thyristor (GTO). This device is used in mainly AC applications such as UPS and traction. Figure 11 performs the structural pin of GTO [6]. It is similar to SCR; it has a limited commission frequency worth less than 6 kHz, and the driver circuit design is composite, and the gate current is turned off [28].

4.8. DIAC. It is a bidirectional toggle path which can be executed in onward and overturn directions. It is mainly used in dimmer applications such as florescent lamps. It is essentially a diode path which is conducted after a breakover voltage, but it still remains in transmission state until the current drops out from the breakover state. It is exhibited in three layers and five layer states; consequently, three layers are pointed out because breakover voltage occurs around 30 V; five layers result in poor performance schemes [18]. Figure 12 indicates the structural pin of DIAC [29].

Table 3: Comparative parameters for switching devices.

S. no.	Parameters	SCR	BJT	MOSFET	IGBT
1	Device used	Minority carrier	Minority carrier	Majority carrier	Minority
2	Voltage or current controlled devices	Current meticulous	Current meticulous	Voltage meticulous	Voltage meticulous
3	Blocking capacity	Symmetrical	Distorted	Distorted	Distorted
4	Temperature coefficient	Negative	Negative	Positive	Flat
5	Commutation circuit	Necessary	Not necessary	Not necessary	Not necessary

4.9. MOS-Controlled Thyristor (MCT). The action of MCT is moderately similar to GTO thyristor; it is prescribed by gate padding. It has the capability to turn on and turn off the voltage and current process. This toggle is used for lofty power relevance such as television, radio frequency, and UPS systems. Figure 13 indicates the structural pin of MCT [11]. When the toggle is on the gate layer which is made negative with respect to anode with the help of pulse, in this stage, the toggle is onward bias. When it is in OFF purpose, the transistor gets shorted; the anode current flows through the OFF FET purpose. In this process, repeal jamming condition gets placed [30, 31].

5. Performance Analysis of Switching Devices

Table 2 initiates the performance analysis of switching analysis of SCR, MOSFET, IGBT, BJT, DIAC TRIAC, and SITH. Table 2 shows the performance parameters for switching devices. It shows the different variation values for power electronics switching families. From the above parameters, the structural plan diagram is indicated in Figure 14.

6. Comparison of Switching Devices

Table 3 mentions the different parameter comparisons for switching devices. It gives the best performance when comparing with other switching devices. Each switching device has its own capability to operate.

7. Comparison of Si, SiC, and Ga-N Materials

As Si, SiC, and Ga-N semiconductor materials are very good supplier in market area, there is a greater benefit for SiC, because it works in well operating conditions because it has a better thermal conductivity than Ga-N and Si-C; it works with low voltage and high power, and the cost is low when compared with other semiconductor devices. While Ga-N system has reached successfully in market area, it has many advantages and it exhibits good properties but the major drawback is that it is achieved with higher cost than Si-C and Si. As Ga-N operates with high frequency, Si-C has no current limit range, but when it comes to wide band gap, Ga-N and SiC are not the same; the material cost for Ga-N is expensive so the wide band gap is very high. Therefore, while using chip devices, Si-C is preferred for many electric vehicles because it operates with good conditions with proper voltage, high power, and efficient temperature, and also the cost is low; therefore, this device is preferred for electric vehicle applications and also in industry purposes.

8. Conclusion

Therefore, the power electronics switching device family is open field with a lot of opportunities in research area. The different types of switching device family take place with performance analysis and comparative analysis with different uniqueness and gain a lot of advantages in unalike switching families. Each toggle performs different contributions according to the structural diagram, and it should be taken into account with a wide range of applications. From the above work, each switching can be connected with power electronics and machine components for electric vehicle applications for future technology, because electric vehicle markets play a vital role in the market area.

Data Availability

All the data supporting the results of this study have been included in this article.

Conflicts of Interest

The authors declare no conflicts of interest.

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