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# A Review of Silicon Carbide and Gallium Nitride Power Semiconductor Devices

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***Abstract*: The main challenge, today in the field of power electronics is the switching losses associated with the semiconductor device, while trying to make the converter compact. The size of any power electronic converter can be reduced by increasing the switching frequency which will in turn lead to the compactness of the device at the cost of increased power loss and decreased efficiency. One way to reduce the loss is by adopting zero current and zero voltage switching which again make the circuit complex. In this paper, two semiconductor devices with reduced switching losses compared to their silicon counterpart are introduced and a review of two novel WBG devices viz; silicon carbide and gallium nitride semiconductor devices are provided which are the two most promising semiconductors for improving the performance of power electronics converters.**

***Keywords*: Gallium Nitride, Silicon Carbide, Switching losses, Wide band Gap devices etc.**

## 1. Introduction

Advancement in any field is directly associated with the reduction and compactness of the devices. One way to achieve this is to increase the switching frequency of the converter, Increasing the switching frequency will reduce the size of inductor and capacitor filter and will improve the output. But since losses is directly proportional to switching frequency, this will in turn conventional method to reduce the switching loss is to adopt Zero voltage switching and Zero current switching making the circuit complex. Now a days power semiconductor devices are like Gallium Nitride and Silicon Carbide are expected to revolutionize the field of power electronics by providing greater energy efficiency and reduced scale power electronic devices and clear energy technologies.

Wide Band Gap semiconductor materials allows the power electronic devices to operate at increased temperature, higher voltages and frequency ,making the converter smaller and more reliable when compared to its silicon counter parts. This in turn boost the development of electric vehicles and other renewable energy technologies at a faster rate. Wide band Gap devices semiconductor have a relatively large band gap semiconductor have a relatively large band gap compared to typical semiconductors. Silicon Carbide and Gallium Nitride are the two basic WBG devices most commonly preferred today .These materials also emit light in the visible colour range, an optical property useful for applications in solid state lighting. Gallium nitride, for example is an enabling material behind the ultra – high efficiency of light emitting diodes (LEDs).

WBG devices are expected to pave the way for exciting innovations in power electronics and other fields across various sectors of industries. Realizing this requires the development of cutting- edge manufacturing processes that can produce high quality WBG materials, devices and modules at an affordable cost.

A comparison of Band Gap of these two with the Silicon is given below. Table 1 shows the comparison of WBG devices with respect to silicon and Table 2 shows their material properties.

Table 1
A comparison of band gap of WBG device and silicon

| Material | Symbol | Band Gap(ev) |
|---|---|---|
| Silicon | Si | 1.1 |
| Gallium Nitride | GaN | 3.4 |
| Silicon Carbide | SiC | 3.3 |

Table 2
Properties of WBG semiconductor devices

| Property | Si | SiC | GaN |
|---|---|---|---|
| Breakdown field(kV/cm) | 300 | 2200 | 2000 |
| Thermal conductivity(w/cm-k) | 1.5 | 4.9 | 1.3 |

## 2. Silicon carbide semiconductor

Silicon Carbide is comprised of two, viz Silicon and carbon together by covalent bonding. It is said that there are many number of polytypes available, depending on the structure of polytype crystal the band gap of SiC may vary from 2.2 ev to 3.3 ev .The favorable characteristics of SiC for power electronic devices is its Higher electric field, high thermal conductivity, higher operating temperature etc which enables these devices to be operated in higher voltages , temperatures etc.

SiC excels over Si as a semiconductor material in 600 N and higher rated breakdown voltage devices. SiC Schottky diodes at 600 V and 1200 V ratings are commercially available today and are already accepted as the best solution for efficiency improvement in boost converter topologies. In addition these diodes find use in solar inverters, because they have lower switching losses than the Si PIN freewheeling diodes now used in that application. At 600 V and 1200 V, IGBTs have been the switch of choice for power conversion. Now that place is slowly being replaced by SiC MOSFETs. The Table 3 shows a comparison of properties of SiC over Si.

Table 3
A comparison of characteristics of silicon carbide with silicon

| Characteristics | SiC vs. Si | Effects |
|---|---|---|
| Operating electric field | 8 times of Si | Due to high dielectric strength, it can be doped to a much higher level leading to lower losses |
| Current density | 2 to 3 times of Silicon | Cost reduction |
| Operating temperature | 400 °C when compared to silicon which is 150°C | Cost reduction |
| Thermal Conductivity | 3 times of Si | Heat dissipation by loss can be conducted with a much lower temperature drop |

Even though several Silicon Carbide based power devices have been successfully commercialized this device is still in its early state and because of that commercially viable devices are less

## 3. Gallium nitride semiconductor

Silicon Carbide devices are suffering from increased cost issues due to the limitation in the availability of quality material. Such a need made the Scientist and Engineers to develop a revolutionary semiconductor power device named GaN that promises to deliver the same performance by reducing energy consumption. The main characteristics of GaN semiconductor when compared to silicon are high voltage operation (but less when compared to silicon carbide), high operating temperature, reduced switching losses with increased switching frequency.

GaN is found to have hetero structure that make it suitable for medium power and voltage applications. GaN dominates the market application coming in the range of 100 V to 1200 V. Higher voltage applications are dominated by Silicon Carbide devices. The main challenge faced by scientists and Engineers who work in this field are the achievement of high threshold voltage for a normally off device. This is necessary for ensuring the safety of hardware and users.

## 4. Challenges and applications

Because of higher operating voltage, higher thermal conductivity a nd high frequency operation ,WBG devices find their major application in the field of microelectronics, optoelectronics, hybrid electric vehicles, FACTS and in other military applications in a wider range. The available SiC devices are SiC JFET, SiC schottky devices, SiC Mosfet, SiC sensors etc. GaN based devices are benefitting in the field of laser printing, optical storage, high brightness. LED, general illumination and wireless based stations. Some other area where GaN is having its application in developmental stage are medicine, memory application and power electronics devices. The main challenge in this field is the cost of these devices when compared to silicon. Silicon Carbide devices are very costly which makes it unsuitable for low cost applications .Research activities are developing in this path and it is expected to meet the demand very soon.

## 5. Conclusion

Wide band gap devices offer numerous advantages in the area of power electronics where high temperature and high frequency operation is needed. Silicon carbide devices find their application in high power applications like power transmission, solid state transformer etc. whereas Gallium nitride devices are mostly used in medium voltage application. With the advent of new technologies it is expected to revolutionize the power electronics market by introducing compact devices with increased efficiency and reduced price.

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