Charging Technology Enabler for Electric Vehicle

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Abstract

High DC voltage is key to ultra-fast charging in Electric Vehicle. This would imply the need for high efficient AC to DC converter and DC to DC converter. Current devices in these converters are silicon based with limited voltage and power handling. Wide bandgap semiconductors, however, are known for their high power density, high breakdown voltage, better thermal conductivity and smaller leakage current. Power devices designed from these semiconductors will have higher power efficiency with higher voltage, power, temperature limits and frequency switching speed. In addition, these devices may result in smaller heat sink and lower cost per watt and fanless equipment for both the charger and the converters in the electric vehicles. Current commercial HEVs/EVs use Si-based insulated gate bipolar transistors (IGBTs) remains the main technology for switching. Higher frequency and breakdown voltage of Si IGBT and MOS-FET have continuously been improved but are close to the limit of Si technology. Moreover, these devices normally come with large cooling systems. It is recognized that wide bandgap material has the potential to provide power devices with even higher frequency and breakdown voltage. The well- known wide bandgap materials are diamond, GaN and SiC, is shown in Table 1. At the moment the leading candidate is SiC. However, the cost is still on the high side. If GaN on sapphire or on Si can be successfully fabricated for high power and voltage, then they would be serious competitors to Si and SiC devices. Table 1 is a comparison of the physical properties of the various wide bandgap materials.

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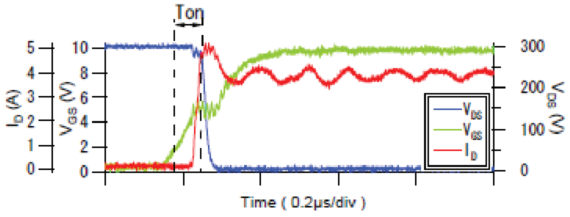
Table 1: Comparison of Physical Properties of Wide Bandgap Materials (1)

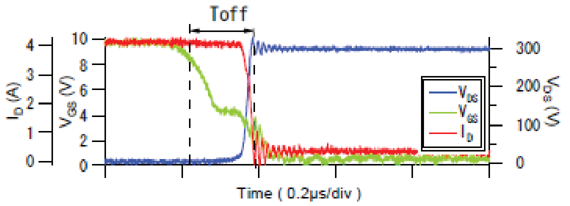
Property	Unit	Si	6H-SiC	4H-SiC	GaN	Diamond
Bandgap	ev	1.12	3.03	3.26	3.45	5.45
Electric Breakdown	Kv/cm	300	2500	2200	2000	10000
Electron mobility	cm^2/Vs	1500	500	1000	1250	2200
Thermal conductivity	W/cmK	1.5	4.9	4.9	1.3	22
Saturated velocity	$10^7 cm/s$	1	2	2	2.2	2.7

Power SiC has made tremendous progress lately, and in particular for vehicle application (2). 300A SiC trench MOSFETs have been fabricated. Using the trench MOSFET design, small on-resistance can be achieved and therefore reduces chip size. SiC substrate has high defect density which is the obstacle to achieving high current switching with on chip. Low on-resistance of $1.7m\Omega mm^2$ with BV=790V and a chip size of $0.5x0.5mm^2$ has been claimed. Similarly, performance of intelligent power module (IPM) can be improved with SiC technology even though there are still issues to be resolved. One known problem is the higher surge voltage due to device parasitic inductance. Limiting surge voltage at high drive current and reliability remains some of the important challenges. In the meantime, good progress has been made in the switching speed of SiC VJFET devices as shown in Fig. 1.

Power GaN also has high breakdown field and carrier saturation velocity compared to Si. Many companies are still evaluating this technology to bring high temperature, voltage and switching frequency to the power electronics market. The key technology that could reduce the cost of GaN is the successful design of GaN on Si substrate. Though there are claims of success in this area, much is yet to be done (4) to bring the cost down (4). Diamond, however, exhibited the best thermal conductivity, breakdown field and saturated electron velocity which would make it a very good device, not because of the cost.



(a) Turn-ON.



(b) Turn-OFF.

Figure 1: Switching Waveform of SiC VJFET (3)

To take full advantage of the SiC or GaN devices, high temperature packaging technologies must be well developed. Emerging technologies such as flip-chip assembly methods, Si_3N_4 substrates, and non base-plates modules would allow operation of HEV and PHEV inverters at elevated junction temperatures (5).

In short, wide bandgap devices are the key to provide small, light-weight power electronics without cooling system for EV and HEV to be a viable competitor to current combustion vehicle.

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About the Author: Dr. Teo received his PhD from University of Alberta in 1990. His recent research involves power devices, wireless power transfer and digital communication technology. He has at least 30 papers and 50 patent applications and patent granted.