



**SIC SEMICONDUCTORS INCREASE UPS RELIABILITY & EFFICIENCY**  
**(SILICON IS ON ITS WAY OUT)**

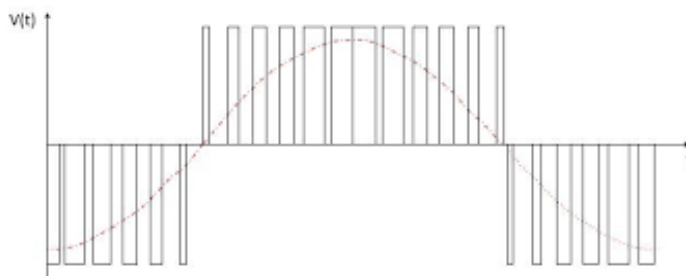
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## ***Executive Summary***

Challenges inside the data center can parallel the challenges in semiconductor manufacturing: maximize efficiency, reduce size, increase power quality/reliability and reduce costs. The data center industry just witnessed the introduction of Wide Bandgap (WBG) semiconductors into the Uninterruptible Power Supply (UPS) marketplace. WBG semiconductors are materials that permit power switching devices to operate at much higher voltages, frequencies and temperature than conventional semiconductor materials. These WBG materials allow for more powerful electrical switching devices to be built that are cheaper and more energy efficient. In this article, we will take a look at the role of the Wide Bandgap semiconductor and its development.

## ***UPS Mission***

UPS manufacturers attempt to provide uninterruptible, conditioned, reliable power to users that have a critical electrical operation in process. If the critical operation gets interrupted, millions of dollars will be lost by the owner. “Mission critical” operations rely on the UPS to keep the mission up and running 100% of the time. In order to supply this reliable power, the UPS uses semiconductors to re-generate the power that comes from the power company. With precise instructions and control from the UPS logic, semiconductors create a conditioned output sinewave every minute of every day. (See figure 1)

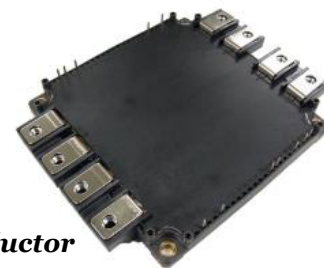


***Figure 1: The output sinewave of a UPS module created by a semiconductor.***

Over the last 50 years, the UPS industry has improved output power quality by upgrading components and fine-tuning the semiconductor. Results include smaller footprints, reduced maintenance requirements, greater reliability and increased end-to-end efficiency. The drive to higher efficiencies has captured most of the attention and direction of the UPS industry.

## ***UPS History***

During the 1960's, '70's, and '80's, the Silicon Control Rectifier (SCR) was the semiconductor of choice for creating the UPS output. It produced a “square-wave” output that required filtering for harmonic distortion. Output efficiency was around 85%. In 1992 the Insulated Gate Bipolar Transistor (IGBT) was introduced. It replaced the SCR as the semiconductor of choice. The IGBT, also Silicon based, improved output efficiency to 94%. In 2008, the industry used the same IGBT in an enhanced configuration known today as 3-level switching. The elimination of internal transformers, combined with the new 3-level switch topology provided a combined efficiency gain up to 97%. The latest step to increase efficiency was made in 2015. A Silicon Carbide (SiC) based MOSFET replaced the Silicon (Si) based IGBT. Efficiency has climbed to 98.6%.



***IGBT Semiconductor***

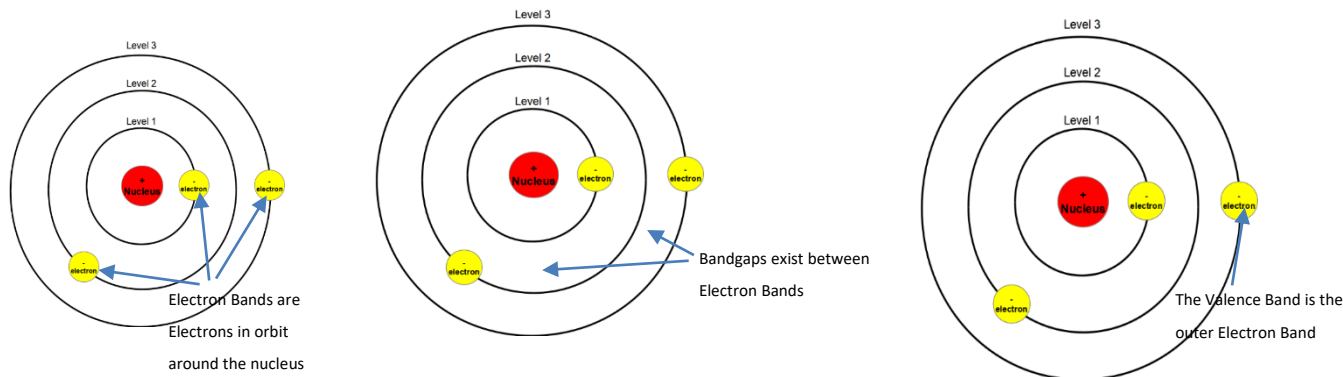
## ***UPS Basics: What is a Semiconductor?***

As the name implies, a semi-conductor conducts current, but only partly. The conductivity of a semiconductor is somewhere between that of an insulator (which has almost no conductivity) and a conductor (which has almost full conductivity). Later in this article, when we learn more about Bandgaps, we will see that a semiconductor is ideal for turning electric current ON and OFF.



**UPS Basics: How does current flow in a Semiconductor?**

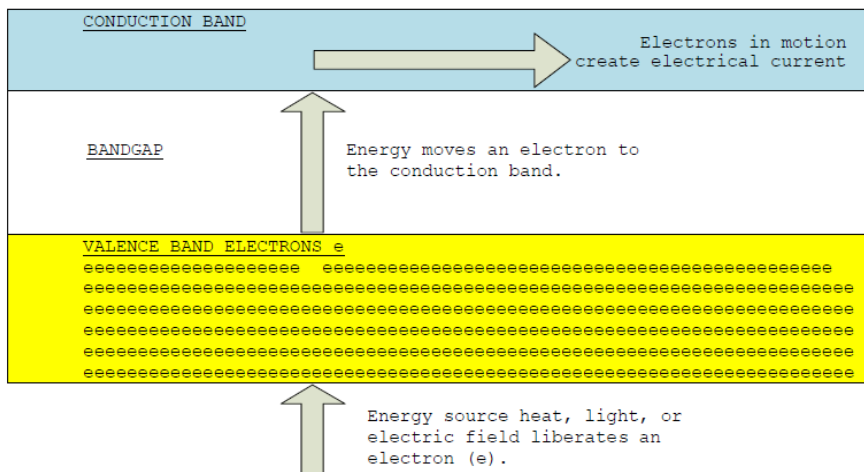
Electric current is the movement of negatively charged electrons from one atom to another. In order to understand this electron flow, we need to understand the atom. All atoms have: a nucleus in the center and electrons that orbit around the nucleus. See figure 2.



**Fig.2**

Notice that electrons exist in different orbital paths. These paths are called Electron Bands (bands of electrons). The space between Electron Bands is called a Bandgap. The further away the electron is from the nucleus, the less attractive force the nucleus has on the electron to keep it in its respective Electron Band. The outermost Electron Band is called the Valence Band.

To create the flow of electrons from one atom to another atom (and make electricity), we select the electrons in the Valence Band because the force holding them to the nucleus is the weakest. The electrons in the Valence Band must cross a Bandgap (space where no electrons can exist) between atoms. Once they cross the Bandgap, they will join other electrons in the Conduction Band and flow from one atom to another. See figure 3.

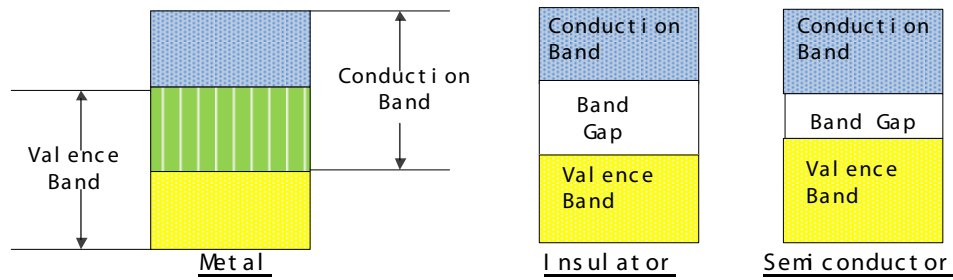


**Fig.3**

Inside a semiconductor, it takes energy to move an electron from the Valence Band to the Conduction Band. The Bandgap that separates the Valence Band and the Conduction Band will determine how a material's electrons behave as electric current. The material selected for the flow of electrons in the Conduction Band is the key to making electricity.

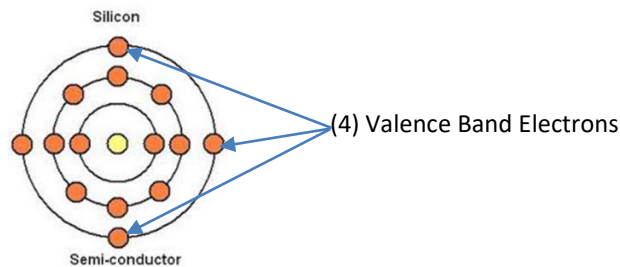
**UPS Basics: Analysis of Materials**

Let us examine different types of materials and see how their Bandgaps hinder or help the movement of electrons from the Valence Band to the Conduction Band. See Figure 4.



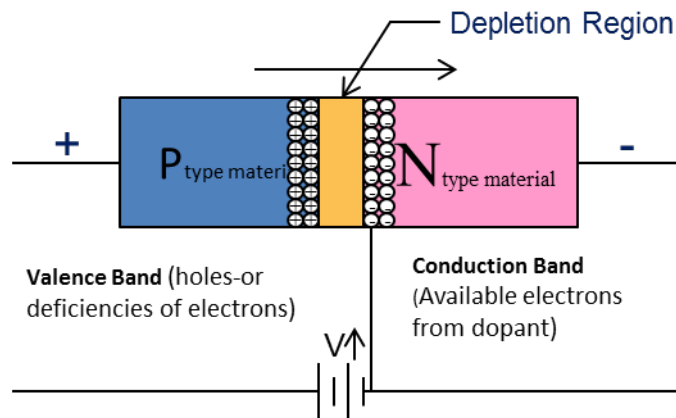
**Fig.4**

Metals (on the left) have a Valence Band and Conduction Band that overlap. This makes them ideal for conducting electricity. There is no Bandgap to cross! A good example of a metal is copper. Insulators (in the center) have a large Bandgap that makes it extremely difficult for electrons to make the journey from the Valence Band to the Conduction Band. Examples of insulators are sand, glass and plastic. A Semiconductor (on the right) has a bandgap that is ideal for manipulation. By that I mean that we can influence the Bandgap to shrink to facilitate the flow of electrons (current) or make the Bandgap wider and to stop the flow of electron current. Silicon (Si) has been the semiconductor material of choice for quite some time now. Note that Si has 4 electrons in the Valence Band of each of its atoms. (See figure 5.)



**Fig.5**

To make electrons leave the Silicon Valence Band and travel to the Conduction Band, we will make use of a component inside the IGBT called the P-N Junction. This is where all the action takes place. See figure 6.



**Fig. 6**



To make the Valence Band electrons more controllable, we “dope” the Silicon material by adding other materials at the P-N Junction of the semiconductor. “Doping” facilitates the movement of electrons across the depletion region (Bandgap). The “P” side (or Valence Band) contains a collection of positive particles called electron holes. The “N” side (or Conduction Band) contains a collection of negatively charged electrons. By applying a voltage (forward bias), the depletion region shrinks and we create current flow. When the voltage is removed, the depletion region returns and the flow of electrons stops. Using the P-N Junction, the IGBT produces a conditioned output current for the UPS. The IGBTs are turned ON and OFF in a controlled manner to support the critical load.

With respect to uninterruptible power supplies, the term double conversion refers to the conversion of the incoming AC voltage to DC voltage and then back to a pure AC sine wave. This has the net effect of eliminating any power fluctuations and enables the UPS to deliver a clean and steady signal to the load, thus providing the highest quality of continuous conditioned power. This voltage conversion process serves to isolate equipment from raw utility power source and provides protection for equipment that may be adversely affected by power sags or surges. Double conversion of the utility power continues to be the best and most reliable method of providing uninterruptable power to critical loads.

**Wide Bandgap Materials**

Over the last 25 years, researchers have discovered that the use of Wide Bandgap materials, such as Silicon Carbide (SiC), allow semiconductor components to be smaller, faster, more reliable and more efficient than the existing Silicon (Si) technology [1]. In solid-state-physics, a Bandgap is an energy range in a solid material where no electron states can exist. The Bandgap generally refers to the energy difference (in electron volts) between the top of the Valence Band and the bottom of the Conduction Band in semiconductors. See Table 1.

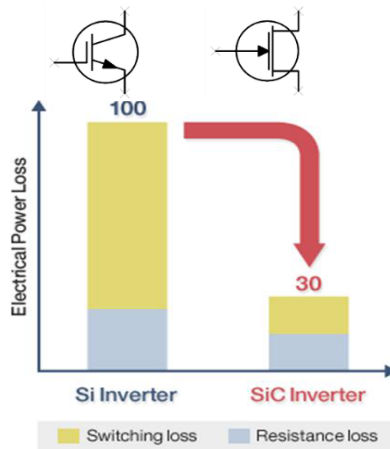
**TABLE 1 Bandgap Energy Levels [2]**

MATERIAL	BANDGAP ENERGY (eV)	APPLICATION
Germanium (Ge)	0.67	First generation electronics, Fiber optics, Transistors
Gallium Arsenide (GaAs)	1.4	Microwave circuits, Thin-film solar cells
Silicon (Si)	1.11	Lasers, LEDs, Integrated circuits, Photo-voltaic cells, Power electronics
Silicon Carbide (SiC)	3.25	LEDs, Power electronics, new emerging technology

The term “Wide Bandgap” used here refers to higher-energy electronic band gaps, usually significantly larger than one electronvolt (eV). “Wide” Bandgap typically refers to material with a bandgap of at least two or three eV, significantly greater than that of the commonly used semiconductor Silicon (1.1 eV). WBG semiconductors permit devices to operate at much higher temperatures, voltages, and frequencies, making the power electronic modules using these materials significantly more powerful and energy efficient than those made from conventional semiconductor materials [3].

**Introducing the Game Changer**

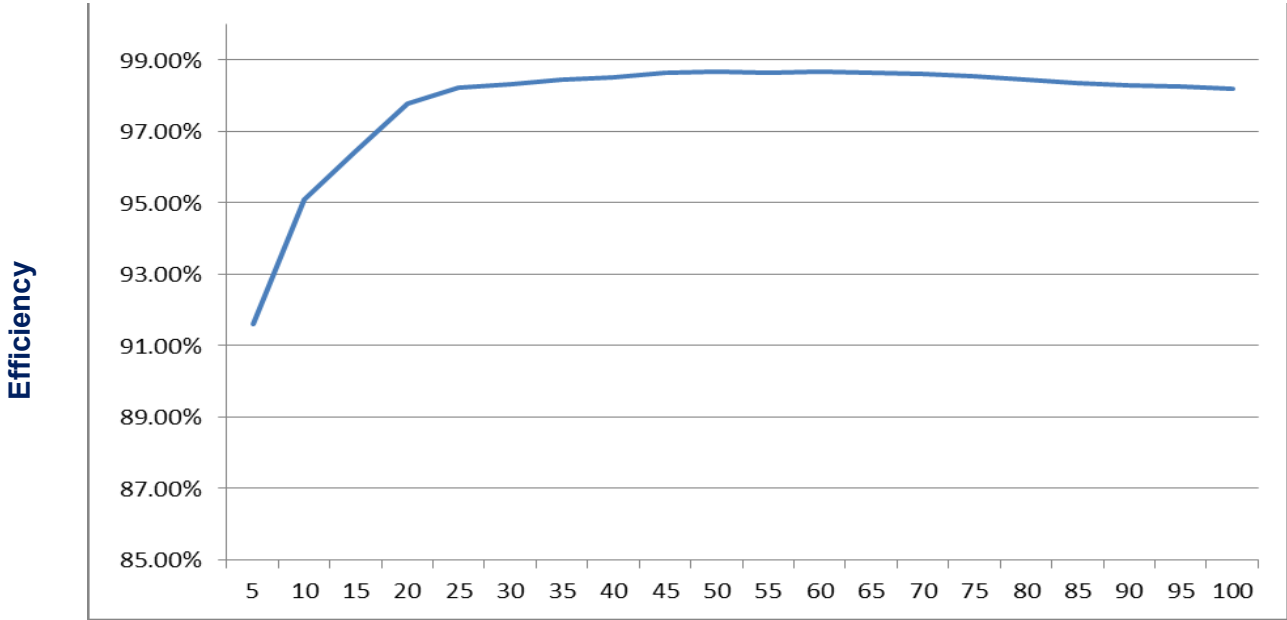
The use of SiC components in double conversion UPS technology allows the user to operate in the double-conversion mode and maintain higher efficiencies. A 100% SiC set of power-switching modules produces a 70% reduction of power losses. (See figure 7.)



SiC reduces semiconductor power losses by 70%

**Fig. 7**

The 70% reduction in power losses of the SiC based UPS directly leads to an increase in the double-conversion efficiency to 98.6%. (See figure 8.) This high efficiency not only occurs at high load situations but also continues on into lower load situations. (See Table 2.) The need for ECO-Mode (utility power instead of inverter power) is gone. The UPS can now provide the same energy savings as ECO-Mode while also providing the critical load with conditioned, more reliable, high-quality power.



% Load	Input kW	Output kW	500kVA Efficiency
0	2.46	0	0.00%
5	29.02	26.58	91.59%
10	52.11	49.55	95.09%
15	78.67	75.87	96.44%
20	104.1	101.8	97.79%
25	124.6	122.4	98.23%
30	154.1	151.5	98.31%
35	180.8	178	98.45%
40	201.7	198.7	98.51%
45	227.5	224.4	98.64%
50	254.2	250.8	98.66%
55	277.7	273.9	98.63%
60	304.3	300.3	98.69%
65	331.3	326.8	98.64%
70	358.3	353.3	98.60%
75	381.8	376.3	98.56%
80	408.6	402.3	98.46%
85	434.7	427.6	98.37%
90	461.8	453.9	98.29%
95	485.4	477	98.27%
100	512.4	503.2	98.20%

**Table 2: 500kVA SiC UPS Efficiency Chart**



Another significant advantage of SiC based UPS is the reduction in heat loss. At 100% load a conventional Si based UPS has a heat rejection of 69.2 kBTU/HR, whereas a SiC based UPS has a heat rejection of 42.0 kBTU/HR. This results in a heat loss energy savings of 39.4% over the Si based UPS. (See Table 3.)

**TABLE 3: SiC UPS Heat Loss Energy Savings (500KVA)**

UPS LOAD (%)	SiC UPS ENERGY SAVINGS (%)
100	39.4%
75	49.9%
50	46.9%

The intrinsic characteristics of SiC based semiconductors also allow them to operate at higher temperatures than conventional Si semiconductors. This reduction in UPS heat loss and the ability to operate at higher temperatures help the customer to decrease their cooling costs which accounts for approximately 35% of a data centers electrical energy consumption.

### **Size and Weight**

When it comes to maximizing the available floor space in a data center, SiC based UPS offer a reduction in weight and size when compared to the conventional Si based UPS. The weight of a 500kVA SiC based UPS is 2770lbs, whereas the weight of a conventional UPS is 3330lbs reducing the floor load by 17%. Moreover, a 500kVA SiC based UPS occupies 14ft<sup>2</sup> compared to the conventional UPS that occupies 20ft<sup>2</sup>. This is a 30% reduction in the required floor space required increasing the available power capacity in a given area. The SiC based UPS can deliver more power within a limited floor space.

### **Summary**

In summary, SiC technology is an innovation that will establish a new trajectory for power electronics. Benefits include: increased system efficiency, lower cooling system requirements, operation at higher temperatures, and higher power density. With the integration of SiC based technology into UPS, the goals of data center operators to operate at higher efficiencies, maximize floor space, and reduce operating costs across the facility are being achieved.

### **REFERENCES**

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