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Characteristics and Applications of Silicon Carbide Power Devices in Power Electronics

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***Abstract*—Silicon carbide materials, with its high mechanical strength, high thermal conductivity, ability to operate at high temperatures, and extreme chemical inertness to most of the electrolytes, are very attractive for high-power applications. In this paper, properties, advantages, and limitations of SiC and conventional Si materials are compared. Various applications, where SiC power devices are attractive, are discussed.**

***Keywords*—Silicon carbide (SiC), SiC properties, high-voltage, high-temperature, high-frequency applications, high-temperature electronics, wide energy band-gap semiconductors.**

I. Introduction

SEMICONDUCTOR devices have a wide range of applications. Several different semiconductor materials are available in the industry [1]-[27]. Silicon has become the most attractive semiconductor material because of its availability and low cost. Moreover, it can be melt in moderate temperatures and its natural oxide, silicon dioxide SiO_2, is a good insulator and can be used for the metal oxide layer [4]. But having a lower melting point does not enable Si to be used in a high-temperature environment or high-power applications.

Silicon carbide was discovered in 1824 by Jöns Jacob Berzelius, a Swede [20], and was identified as SiC by Acheson in 1885. Hence, SiC could be argued as the great grandfather of all semiconductors. SiC has been known for its high physical strength and thermal stability compared to Si, which makes it suitable for high temperature, high voltage, and high power applications [1]-[12], [14]-[27]. Its unique physical structure exhibits high chemical inertness, which enables reliable performance in adverse environments. Amazingly, SiC also has SiO_2 as its natural dioxide, which makes it compatible with Si. However, SiC is not available as a natural mineral and requires extensive furnace techniques for its production. The same properties, which make SiC suitable for high temperature applications, make it difficult to grow the mineral from the melt.

The objective of this paper is to present an overview of SiC technology and to compare it with Si technology. Different electric and thermal characteristics of SiC and Si, potential applications of SiC with its attractive properties, and the current challenges in the usage of SiC are discussed. Also, some examples of applications, where SiC can be used are presented.

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II. SiC Characteristics

SiC is a compound semiconductor material that has many properties, which makes it suitable for different applications. The primary characteristic is the wide energy band gap, which determines the amount of energy required to raise an electron from the valence bond into the conduction band. The wide energy band gap, 3.0-3.2 eV, facilitates the operation of SiC in higher temperatures and higher radiation levels. A wide energy band gap results in reduced intrinsic carrier concentrations for higher temperature operation and reduced leakage current. Radiation does not degrade the electrical properties of SiC devices. SiC also operates at very high power levels for the same reason.

The critical electric field (dielectric strength or maximum electric field) of SiC is higher than that of Si by at least an order of magnitude, resulting in higher doping and thinner drift regions for a given blocking voltage. This leads to a reduction in specific on-resistance of the components [19]. As a result, the die size can be reduced by at least one order.

SiC can emit bright blue light, which makes it attractive, since the blue LEDs were missing among existing light emitting diodes. Also, SiC has a high maximum electron velocity, which enables operation at high frequencies. Another desirable property of SiC is its high thermal conductivity, which means it can dissipate the excess heat easily and high breakdown electric field enabling its operation at high voltage levels. The durability/stability of SiC contacts and semiconductor-insulator interfaces extends the device lifetime.

III. Comparison of Electric and Physical Properties of 4-H SiC, 6-H SiC, GaAs and Si

Silicon carbide, with its attractive characteristics, has many advantages when compared with Si based devices. Among the various polytypic forms of SiC, 4H-SiC and 6H-SiC are most commonly used materials because of the availability and quality of the single crystal wafers. 4H-SiC is the chosen polytype for the most of the research activity with its higher electron mobility and more isotropic nature compared to 6H-SiC. The electron mobility of 4H-SiC is twice of that of 6H-SiC. A summarized comparison of the electronic and physical properties of 4H-SiC, 6H-SiC, GaAs, and Si [26], [24] is given in Table I.

SiC has a wide energy band gap which makes it capable of surviving in high-temperature, high-voltage, and high-power environments. The energy band gap of SiC is in the range of 3.0-3.2 eV, whereas for Si it is about 1.12 eV. Due to its high electric breakdown field, SiC power devices have high breakdown voltages. Schottky diodes are preferred over p-n junction diodes for high-frequency applications because of

TABLE I
COMPARISON OF ELECTRONIC AND PHYSICAL PROPERTIES OF 4H-SIC, 6-H-SIC, GAAS, AND SI

Property	4H-SiC	6H-SiC	GaAs	Si
Band gap energy (eV)	3.26	3.03	1.43	1.12
Breakdown electric field, E_{max} (V/cm)	2.2×10^6	2.4×10^6	3×10^5	2×10^5
Thermal conductivity, G_{th} (W/cmK)	3.45	3.45	0.5	1.5
Saturation electron drift velocity (cm/sec)	2×10^7	2×10^7	1×10^7	1×10^7
Electron mobility, μ_e (cm^2/V-s)	800 ⊥ to c-axis 800 ∥ to c-axis	400 ⊥ to c-axis 60 ∥ to c-axis	6500	1200
Figure-of-merit, F_M (MW/cm^2)	2000	-	-	5
Dielectric constant, ε_r	9.7	9.7	12.8	11.8
Commercial wafers	1.375″	1.375″	6″	12″

their negligible reverse recovery, reducing switching losses and electromagnetic interference (EMI). Since Si Schottky diodes exhibit low breakdown voltage ($V_B < 200$ V), SiC Schottky diodes can be used in high-voltage applications (600-1200 V).

SiC devices are thinner and have low specific on-resistance when compared to Si devices. The on-resistance of SiC unipolar devices are in the range of $1.12\ \mu\Omega$ and $29.5\ \mathrm{m}\Omega$ as the breakdown voltage increases from 50 V to 5000 V, which is 100-300 times less than comparable Si devices [21]. The high electron mobility enables SiC devices to operate at high frequencies, higher than 100 kHz, which is not easily achievable with Si based devices. Minority carrier SiC devices are usually 100 times faster than corresponding minority carrier Si devices. SiC also has high thermal conductivity, about 3.45 W/cm-K compared to that of Si, which is about 1.5 W/cm-K. Also, SiC devices have a junction-case thermal resistance of 0.02 K/W, which is lower than that of Si with a thermal resistance of 0.06 K/W. As a result, SiC can operate in higher temperatures and the rate of device temperature increase is lower than that of Si [21]. Therefore, the forward and reverse characteristics of SiC devices experience only slight variation with temperature and time, resulting in more reliable devices than Si.

The specific on-resistance describing power switching devices is defined as the on-resistance-area product

$$S = R_{on}A, \tag{1}$$

where R_{on} is the on-resistance and A is the device area. An example for the specific resistance of SiC power MOSFET is $125\ \mathrm{m}\Omega$-cm^2 for 760 V.

Baligas figure-of-merit defined in 1989 [11] can be expressed as

$$BFOM = \varepsilon_r \mu E_{max}^3, \tag{2}$$

where ε_r is the dielectric constant of the semiconductor, μ is the drift region mobility, and E_{max} is the critical electric field of the semiconductor. *BFOM* can be used to compare the relative performance of various semiconductor materials for power device fabrication.

Another figure-of-merit of semiconductor switching devices is defined as

$$F_M = \frac{V_B^2}{R_{on}A} = \frac{V_B^2}{S} = \frac{\varepsilon_0}{4} BFOM, \tag{3}$$

where V_B is the off-state breakdown voltage and $\varepsilon_0 = 8.854\times 10^{-12}$ F/m is the permittivity of free space. For the above example with $V_B = 600$ V and $S = 125\ \mathrm{m}\Omega$-cm^2, $F_M = 4.6\ \mathrm{MW/cm^2}$.

For Si unipolar devices such as MOSFET, the figure-of-merit is

$$F_{M(Si)} = 5\ \frac{\mathrm{MW}}{\mathrm{cm}^2}. \tag{4}$$

For SiC unipolar devices such as MOSFET, the figure-of-merit is

$$F_{M(SiC)} = 2000\ \frac{\mathrm{MW}}{\mathrm{cm}^2}. \tag{5}$$

Therefore, the ratio of SiC figure-of-merit to Si figure-of-merit is given by

$$\frac{F_{M(SiC)}}{F_{M(Si)}} = 400. \tag{6}$$

Another parameter describing semiconductor switching devices is the on-resistance per unit area

$$\chi = \frac{R_{on}}{A}\left(\frac{\mathrm{m}\Omega}{\mathrm{cm}^2}\right). \tag{7}$$

For SiC unipolar devices such as MOSFETs, the on-resistance per unit area is

$$\chi_{(SiC)} = 3.1\left(\frac{\mathrm{m}\Omega}{\mathrm{cm}^2}\right). \tag{8}$$

For Si unipolar devices such as MOSFETs, the on-resistance per unit area is

$$\chi_{(Si)} = 248\left(\frac{\mathrm{m}\Omega}{\mathrm{cm}^2}\right). \tag{9}$$

Therefore, the ratio of SiC on-resistance per unit area to Si on-resistance per unit area is given by

$$\frac{\chi_{(SiC)}}{\chi_{(Si)}} = 80. \tag{10}$$

A recently developed SiC power MOSFET features an on-resistance of $3.1\ \mathrm{m}\Omega/\mathrm{cm}^2$ and withstands a breakdown voltage of 900 V.

The switching power device on-resistance is given by

$$R_{on} = R_{dr} + R_{ch} + R_c, \tag{11}$$

where R_{dr} is the planar drift region resistance, R_{ch} is the channel resistance, and R_c is the ohmic contact resistance. The drift resistance is the dominant component of the device on-resistance in high voltage devices.

The doping level in the drift region N_D required to support a given breakdown voltage V_B is given by

$$N_D = \frac{\varepsilon E_{max}^2}{2qV_B}, \tag{12}$$

where $q = 1.60218\times10^{-19}$ C is the magnitude of the electron charge. The doping level N_D is inversely proportional to the breakdown voltage V_B. The depletion layer width W_D at the breakdown voltage V_B is given by

$$W_D = \frac{2V_B}{E_{max}}. \tag{13}$$

The required depletion width is proportional to the breakdown voltage. The resistance of a planar drift region, neglecting the edge effects, is given by [1]

$$R_{dr} = \frac{4(V_B + V_{bi})^2}{A\mu_e \varepsilon E_{max}^3}, \tag{14}$$

where A is the device active area, V_B is the device breakdown voltage, V_{bi} is the built-in potential, μ_e is the electron mobility, and $\varepsilon = \varepsilon_r \varepsilon_0$ is the semiconductor permittivity. Hence, the ratio of the drift resistance of the Si device to that of SiC device with the same voltage ratings and device areas is calculated as

$$\frac{R_{dr(Si)}}{R_{dr(SiC)}} = \frac{\mu_{e(SiC)}}{\mu_{e(Si)}} \frac{\varepsilon_{(SiC)}}{\varepsilon_{(Si)}} \left(\frac{E_{max(SiC)}}{E_{max(Si)}}\right)^3. \tag{15}$$

At 150°C and 600 V, $\mu_{e(SiC)} = 148$ cm^2/(V · sec), $\mu_{e(Si)} = 576$ cm^2/(V · sec), and

$$\frac{R_{dr(Si)}}{R_{dr(SiC)}} = \frac{148}{576} \times \frac{9.7}{11.8} \times \left(\frac{2.2 \times 10^6}{2.4 \times 10^5}\right)^3 = 162.69. \tag{16}$$

This relationship holds true at high breakdown voltages. However, the ratio of the two drift resistances decreases as the breakdown voltages decreases [15].

Assuming that the total on-resistance R_{on} is approximately equal to the drift resistance R_{dr}, the conduction power loss is given by

$$P_{Rdr} = R_{dr} I_{rms}^2, \tag{17}$$

where I_{rms} is the rms value of the current flowing through the device. For the same amount of current, the ratio of the conduction power loss in the Si device to that in the corresponding SiC device is

$$\frac{P_{Rdr(Si)}}{P_{Rdr(SiC)}} = \frac{R_{dr(Si)}}{R_{dr(SiC)}} = 162.69. \tag{18}$$

SiC devices have higher thermal conductivity and thus a lower junction-to-case thermal resistance $R_{th(jc)}$. Hence, heat is more easily conducted from the device junction to the case, resulting in a lower rise of the junction temperature T_J. The maximum junction temperature T_{Jmax} can be much higher for SiC (up to 600°C) than for Si devices (about 200°C) because of wider energy band gap. SiC devices are more reliable because their characteristics are less sensitive to temperature and ageing compared to Si devices. The temperature rise within the semiconductor device due to the conduction power loss is expressed by

$$\Delta T = \frac{h}{G_{th} A} P_{Rdr}, \tag{19}$$

where G_{th} is the thermal conductivity of the semiconductor material and h is the chip thickness. The ratio of the temperature rise for the Si device to the temperature rise for the SiC device with the same thickness and same power loss can be obtained as

$$\frac{\Delta T(Si)}{\Delta T(SiC)} = \frac{G_{th(SiC)} A_{(SiC)}}{G_{th(Si)} A_{(Si)}}. \tag{20}$$

Assuming the temperature rise in both the SiC and Si devices to be the same, the ratio of the device areas is

$$\frac{A_{(SiC)}}{A_{(Si)}} = \frac{G_{th(Si)}}{G_{th(SiC)}} = \frac{1.5}{3.45} = 0.4348. \tag{21}$$

On the other hand, if the device areas of both the devices are the same, the ratio of the temperature rise in the devices can be obtained as

$$\frac{\Delta T_{(Si)}}{\Delta T_{(SiC)}} = \frac{G_{th(SiC)}}{G_{th(Si)}} = \frac{3.45}{1.5} = 2.3. \tag{22}$$

For semiconductor devices, the capacitance is proportional to the device areas. Since the required area for the SiC devices as compared to its Si counterparts is 2.3 times lower, the capacitance is also 2.3 times lower. The switching loss in a semiconductor device is given by

$$P_{sw} = \frac{1}{2} f C V^2. \tag{23}$$

Hence, the switching loss in the SiC device is 2.3 lower than that in a Si device for the same frequency and voltage. SiC devices suffer much less from reverse recovery than Si devices, reducing switching losses and electromagnetic interference (EMI) as well as eliminating the need for snubbers.

Though SiC has many advantages over Si, experiments done on the first generation of SiC diodes show that Si devices are superior to SiC in the steady-state region because of lower threshold voltage and SiC devices are superior to Si in the transient region. For low-voltage applications and especially lower frequencies, Si devices proved to be the better choice to attain high efficiency [14].

IV. Applications

Some of the potential applications of SiC power devices are:

- High-power uni/bipolar devices for electric vehicles.
- Electric power distribution.
- High power microwave electronic devices for radar, communications, and UHF broadcast systems.
- High temperature sensors and control systems for automobile, aerospace, aircraft engines, fuel combustion, deep-well drilling, and manufacturing.
- High-pressure sensors.
- High-power RF systems.
- High-voltage rectifiers.
- MEMS.
- Blue LEDs and substrate for the active compounds.
- Schottky diodes.
- Avionics systems.
- Household appliances.
- Active power factor correction.
- Rail tractions and locomotives.
- Electronic ballasts.
- Display drives.
- Cooling systems.

A. High-Power Electric Vehicles

Hybrid electric vehicles (HEV), full electric vehicles (EV), and fuel-cell vehicles (FCV) have to overcome various challenges such as their size, weight, selection of electronic systems and controls, and thermal management to gain the expected popularity. SiC components are considered to be a solution. With its high thermal conductivity, it can dissipate excess heat easily. This reduces the need for excessive thermal management systems as compared to Si based systems. Due to its wide energy band gap, SiC materials can survive high voltage and high temperature conditions in the engine. Thus, SiC technology can improve the HEV system efficiency, while reducing the size, weight, and cost [21].

B. Renewable Energy Sources

Power converters such as dc-dc converters and dc-ac inverters are inevitable components in interfacing renewable and alternative energy sources to the utility power grids. High efficiency and low resistance along with the ability to withstand high voltages and temperatures make SiC devices more attractive and reliable than Si devices in power converters for grid applications.

C. High-Power Microwave Electronic Devices

Its ability to operate at very high frequencies due to high maximum electron velocity makes SiC perfect for high power microwave transistors used in radar and communications. Transistors, which can operate at a maximum frequency of 3.2 GHz, have been developed and demonstrated.

D. High-Power RF Systems

Two adverse effects of reverse recovery of rectifiers are reduced efficiency and electromagnetic compatibility (EMC). Since SiC rectifiers have minimal reverse-recovery charge Q_{RR}, the active snubbers to control the turn-off rate of the rectifier can be avoided. By using SiC rectifiers, the operating frequency of the converters could be increased and size could be reduced, e.g., in boost power factor correctors (PFC) [12]. Using SiC power devices in switching power converters reduces the total losses as the switching losses are very low, resulting in very high efficiency. Also, the sizes of the passive filtering components can be reduced, since the SiC devices can operate at very high frequencies without much increase in switching losses. Usually, these sizes are inversely proportional to the operating frequency [22]. Recently, Cree, Inc. has demonstrated 4H-SiC MESFETs with $f_t = 22$ GHz and $f_{max} = 50$ GHz. Class A and class B RF power amplifiers operating in GHz range with output power 15 W and added efficiencies about 50 % have been also demonstrated.

E. SiC Schottky Diodes

Schottky diodes are characterized by their capability of high speed switching with negligible reverse recovery. This property of Schottky diodes makes it attractive for switching applications. But the practical applications of Schottky diodes were limited to low voltage switching systems (< 200 V) because of the moderate field strength of Si. Now, SiC Schottky diodes are already in the market which is capable to handle 300 V-1200 V/1 A-20 A. The high speed Schottky diode with its low on-resistance and low switching capacitance, significantly reduces the conduction and switching losses, resulting in high system efficiency. Also, the use of SiC material enables high temperature operations. Thus, SiC Schottky diodes with its low power losses, high-temperature, high-power, and high-frequency performance are highly efficient in active power factor correctors.

In a simulation using the Infineon Spice model for SiC Schottky diode, it was found that the diode exhibited no reverse recovery until it was operated at 10 MHz. Even at 100 MHz, it retained its rectifying property, though there was reverse recovery. Typical threshold voltage of the SiC p-n junction diodes is 2.5-2.6 V for 6H-SiC and 2.8 V for 4H-SiC which is much higher than in Si p-n junction diodes. Therefore, the conduction power losses in SiC p-n junction diodes are much higher than Si p-n junction diodes. For SiC Schottky diodes, typical threshold voltage is 1.5-2 V. This disadvantage of SiC is especially important in low-voltage applications.

F. Power Factor Correctors

SiC Schottky diodes are being using in power factor correctors such as boost power factor correctors. This is because SiC diode has significantly reduced reverse recovery problems. The output voltage of power factor corrector is typically 400 V.

G. Blue Light Emission

With semiconductor materials, bright light emitting diodes that produce red and green lights have been commercially available for many years. The ability of SiC to emit blue light provides the missing component to display or replicate the full range of color spectrum. This leads to various applications such as full color flat-panel displays, color document scanners, color recognition sensors, digital color photographic printers, automotive lighting, and high-power lighting. Also, blue laser systems with their shorter wavelength compared to red one, may enable greater storage densities for storage applications such as CD-ROMs.

H. MEMS

The well-known attractive properties of SiC makes it a good candidate for MEMS applications, both as a structural material and as a protective layer. Various researches resulted in the development of SiC based micro-electromechanical system devices to improve the shock survivability and operating temperature as compared to that based on Si technology. The SiC devices developed in this area include SiC high-temperature and pressure sensors [23], accelerometer, etc. However, the physical strength of SiC makes it difficult to do the thermal diffusion, etching, and other manufacturing processes.

I. Avionics Systems

To improve the dynamic range of VHF/UHF receivers, high band gap mixer diodes could be used instead of the Si mixer in the VHF/UHF receivers. High energy band gap mixer diodes could be constructed using SiC material [8].

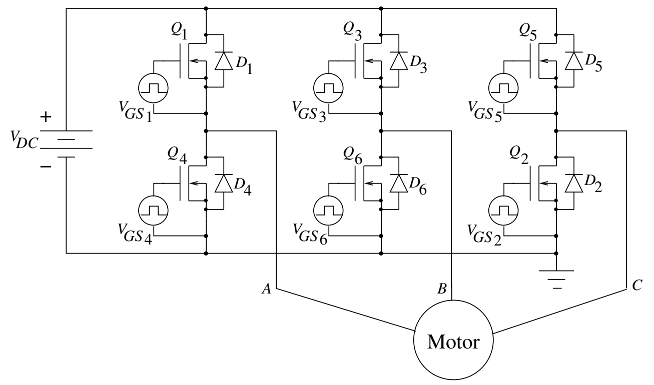

Fig. 1. Three-phase dc-ac inverter driving an induction ac motor or converting a dc photovoltaic voltage to ac utility line voltage.

J. Sensors

With its high physical strength and thermal conductivity, SiC based high temperature sensors enable the direct monitoring of combustion processes and thereby a more accurate control. These sensors could be used for monitoring engine combustion process, which needs quick response time [20]. Its hardness and robustness also enables its use as high pressure sensors.

K. Photo Detectors

Most of the SiC wafers available have their spectral photosensitivity concentrated in the wavelength range beyond the visible spectrum. This enables them to be a promising material for UV radiation detectors [10].

V. Examples of Applications

An example of applications of SiC devices is a three-phase dc-ac inverter driving an induction ac motor as shown in Fig. 1. This circuit can be used for traction drive systems such as hybrid electric vehicles (HEVs). It can also be used to convert a dc photovoltaic voltage to ac utility line voltage.

The typical specifications of the ac motor are 30 kW, 230 V, and 3000 rpm. The typical specifications for a dc-ac inverter are 30 kW continuous power, at least 55 kW power for 18 s, dc supply voltage 400 V and 200 A for each parallel combination of transistor and diode, 300 A per motor phase, cost $<$ \$7 /kW for integrated ac motor, dc-ac inverter and controller circuits, and lifetime of 15 years. The inverter is controlled by pulse-width modulation technique. SiC power MOSFETs and SiC Schottky diodes can be used as power switching devices. The conduction losses can be reduced due to low on-resistances and the switching losses can be reduced due to lower capacitances. The inverter will be much more reliable because of much higher maximum junction temperature T_{Jmax} and higher breakdown voltages. The benefits of using SiC devices include reduction in size, weight, and cost of switching devices and heat sinks as well as increase in reliability.

Another example is a Class D RF amplifier used in radio and TV transmitters for broadcasting applications. The basic circuit of a class D RF amplifier is shown in Fig. 2. The frequencies in concern range from 500 kHz to several GHz.

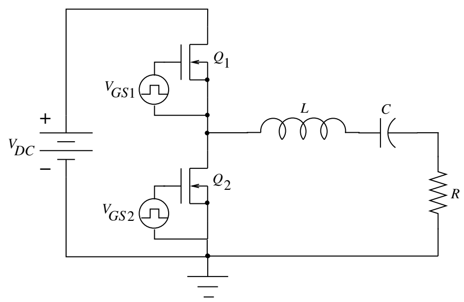

Fig. 2. Class D RF power amplifier.

SiC devices are attractive candidates for the switching devices in this circuit because of its low conduction and switching losses and hence the capability of high-frequency operation. SiC power MOSFETs normally require a high gate-to-source voltage up to 24 V. Therefore, it is more difficult to drive them and they are less suitable for low-voltage applications.

VI. Challenges

The properties of SiC, which makes it attractive for high-voltage, high-power, and high-temperature applications, pose the main challenges in SiC device manufacturing. The various challenges in SiC device manufacturing can be listed as follows:

A. Low Availability

Silicon carbide is not available as a natural mineral and due to its mechanical and thermal properties, excessive furnace techniques are required to produce the compound from Si. Also, due to the defects resulting from the present processes, manufactures are not able to produce a large wafer. Though, SiO_2 is a natural oxide of SiC, which makes it compatible with Si, the production of SiO_2 from SiC results in material defect due to the presence of carbon.

B. Difficulty in Doping

Doping is another difficulty in SiC device fabrication because of its physical strength, chemical inertness, and low diffusion coefficient of other impurities. The common doping techniques used include epilayer doping, ion implantation, laser doping, etc. [27]. Due to its low diffusion coefficient, it is not practical to do thermal diffusion in SiC. Therefore, ion implantation is used to make DMOS power transistors.

C. Defects in the Substrate

With the present manufacturing processes, different types of material defects are resulted in the obtained SiC substrates. These defects can be classified as wafer-level defects and epitaxial-related defects. Some of these defects can be avoided by using good epitaxial techniques. But the most prominent wafer-level defect like micropipes adversely affects the reverse blocking characteristics of the device [17]. Another defect, screw dislocation, reduces the breakdown voltage by 5 % to 35 %, higher reverse leakage current, and highly localized microplasmic breakdown current filaments.

D. High Substrate Costs

High manufacturing and processing costs result from extensive furnace techniques and processing required to anneal the defects. Since both the thermal and electrical properties of SiC is much different from Si, the available methods might not be suitable for SiC. Thus difficulty in producing large wafers with less defects and lack of suitable manufacturing processes result in high manufacturing costs.

E. Contacts, Interconnects, and Passive Components

Usually, contacts and interconnects are provided to carry signals back and forth between the devices. Even though SiC is capable of handling extreme adverse environments, that will become functionally useless if the contacts and interconnects cannot handle the same extreme conditions. Thus, the durability and reliability of the contacts and metalization capable of handling extreme conditions are also the main concerns in SiC technology. Also, the passive components like inductors and capacitors should be able to handle the extreme conditions if they are to be used with SiC semiconductor devices.

VII. Conclusions

The attractive characteristics of SiC and its advantages and limitations in comparison with Si have been discussed. SiC devices exhibit many electrical and thermal benefits. Though there are so many characteristics that makes SiC preferable to Si, the availability and easier processing techniques of Si, makes it challenging to fully exploit the physical and chemical properties of SiC as of todays technology. The various applications, where SiC devices could be attractive have been explored. SiC Schottky diodes are on the market and are used in many applications such as PFCs. Commercial SiC power MOSFETs, IGBTs, and MESFETs are still under development. SiC MOSFETs are entering the market.

Compared to Si Schottky diodes, SiC Schottky diodes can have high breakdown voltages and are capable of operating at high temperatures. The threshold voltage of SiC Schottky diode is higher than that of the corresponding Si diodes, resulting higher conduction losses. SiC Schottky diodes are very fast and are suitable for fast switching applications. SiC power MOSFETs are expected to have the on-resistance lower by a factor of 100 as compared to Si power MOSFETs, thus considerably reducing conduction power losses. With the various research efforts going on in this area, it will not be too long before Si devices could be replaced by SiC in high-voltage, high-temperature applications.

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