

Silicon Carbide: Properties and Applications

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1: Introduction

The ever increasing challenges faced in technical areas where equipments have to work under harsh conditions offer great prospects of development and scientific understanding. The search for electronic components capable of meeting the challenge open applications in space, telecommunications, transport, high temperature and/or high power environments, etc. For this purpose, research has been initiated since the seventies on wide bandgap materials such as silicon carbide, gallium nitride, aluminum nitride, etc. So far, the results have shown that silicon carbide with its excellent physical and chemical properties is the best choice for the production of electronic components for above applications.

It is known that tight chemical bonding makes semiconductors of the diamond type chemically inactive at high temperatures (Tairov & Willander, 1997), but they have interesting properties to enforce such as hardness, mechanical strength and resistance to radiation. These physical properties ensure their widespread use without damage in space, aviation, military, automotive and stressful industry applications. Properties such as high value of electric field breakdown, high saturation velocity (drift speed limit) and high thermal conductivity are of great importance for high power, high temperature and high frequency applications.

Though silicon carbide has the best properties for above applications, one has to know all about its technological process such as its preparation, purification, growth, n and p doping, oxidation, metallization, etc. Problems related to the formation of structural micropipes, interface substrate-active layer state, best substrate to use, nature of metal contact to use for high temperature applications, etc. are also important to know for a better design of devices.

2: History

Silicon carbide is not a new material as one might think from its recently use in modern electronics. Its discovery dates back to 1824 due to a Swede named Jöns Jacob Berzelius (Bano, 1997; Tairov & Willander, 1997). In 1885 Acheson discovered some of its properties. He gave it his current chemical formula SiC (Davis et al., 1991). SiC does not exist in nature. It is necessary to use chemical reactions at high temperature to grow it. It was discovered in a meteorite in 1905 as physical material (System plus, 1999). Its primary use was in abrasives and cutting disks (System plus, 1999). Its first application in the field of electronics was in 1907 as a material for light-emitting diodes (System plus, 1999).

In the fifties the Soviets were interested in the material and in 1955 Levy set up the first method based on a process of sublimation for growing crystals of high purity (Bano, 1997). From that moment on, interest for SiC as a material for future electronic became certain, despite the technological difficulties of the time. Scientific meetings on the topic take place more often and in the sixties and seventies consider SiC as a material of the future and call for its development. In 1978, Tairov and Tsevtkov found a new growth method, called Levy's modified method (Davis et al., 1991), which led to the production of large size high quality substrates. It was a revolution because it enabled the fabrication of true bulk crystals. Through the nineties, electronic devices such as bipolar transistors, MOSFETs, MESFETs, PN diodes and Schottky diodes have been developed with the help of volume and surface structural characterization methods (microscopy, X ray, TEM, SEM, AES, RBS, etc.) and optical and electrical characterization (absorption, IR, Raman, photoconductivity, Hall effect,

resistivity, DLTS, I-V, C-V, etc.). Silicon carbide electronic components are still special and much remains to be done to reach maturity that allows them to take their expected place in the public domain alongside conventional components such as silicon and gallium arsenide.

3: Crystal structures of silicon carbide

Silicon carbide is a binary compound. There are several structures called polytypes. They are more than 200 SiC polytypes (less than a dozen are currently being synthesized). Polytypism is a special case of polymorphism. All polytypes consist of an identified double layer of atomic bonds whose growth sequence is different along a certain direction, i.e., crystals do not differ in the number of atoms of silicon and carbon but in the arrangement of atomic layers. Each carbon atom in a tetrahedral structure surrounded by four silicon atoms and each silicon atom is bound in a tetrahedral structure with four atoms of carbon by sp^3 orbital bonds (Tairov & Willander, 1997) (figure 1).

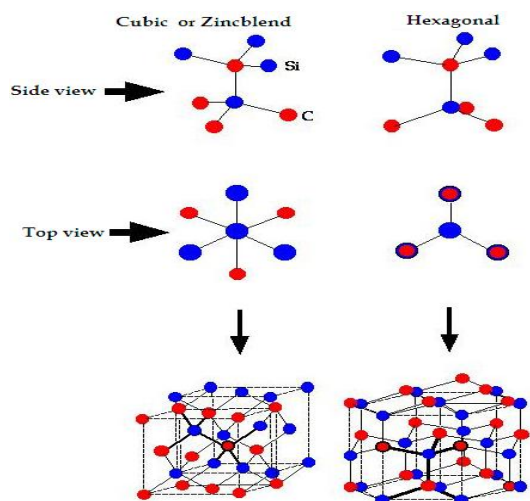


Fig.1: Silicon Carbide crystalline structure

Planes are stacked in three distinct manners labeled A, B, C. Among simplest and well known Polytypes, we have sphalerites or 3C cubic or zincblende structures labeled α , wurtzites or 2H then 6H, 4H and 15R called hexagonal structures and known with label β . Figure 1 shows atoms positions in cubic and

hexagonal crystal structures (System plus, 1999).

3C have three cubic layers; 2H, 4H, 6H, have two, four and six hexagonal layers, respectively. 15R has 15 rhombohedral layers. The number represents number of bilayers in an elementary sequence in the crystal structure, Figure 2. The most used in electronic technology are compounds 3C-SiC, 4H-SiC and 6H-SiC, Figure 3. Based on work performed, it is shown that among the four polytypes, 6H is the easiest to synthesize a crystalline structure point of view, while the 3C and 4H are more attractive to their electronic properties (Tairov & Willander, 1997).

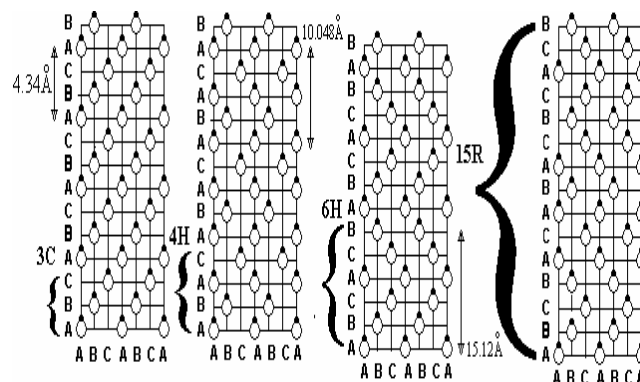


Fig. 2: Simplified electronic layers Stacking sequences of SiC crystalline structure.

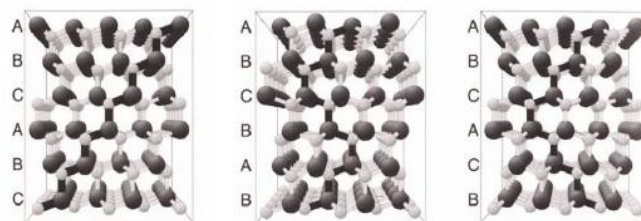


Fig. 3: 3C, 4H and 6H Silicon Carbide crystalline structure (Choyke et al, 2004)

4: Silicon Carbide devices

The study, design and manufacture of a device come from a need. Conventional devices based on silicon can no longer meet the requirements of change in electronic components needed in today high frequency, high temperature, high dissipation and high power applications for

places like space, nuclear plants, power plants, etc. Judging from literature of the past twenty years on silicon carbide, significant technological progress has been made in the field of crystal growth, deposition, doping, oxidation, metallization, substrate size, etc. This has resulted in the realization of many devices such as blue laser diodes, Schottky diodes, rectifier diodes, MOSFETs, MESTFETs, bipolar transistors, SITs, etc. In this section we present the fabrication of a number of devices and give their electrical performances.

4.1: Schottky diodes

Most silicon carbide Schottky diodes reported in literature are manufactured for high power and high frequency use (Wang & Liu, 2002). Schottky SiC diodes have some advantages compared to silicon or GaAs diodes. Since their electrical properties are based on majority carriers, they have fast switching times, exhibit no reverse recovery current and have low power dissipation. Silicon Schottky diodes have breakdown voltages of about 200V (Wang, 2002). For silicon carbide, clamping voltage depends on doping of epitaxial layer. For 100 μm layer doped with $7.10^{14} \text{ cm}^{-2}$, breakdown voltage is about 4500V with a current of 25 A. cm^{-2} and an on-state voltage of 2.4V. For this diode, protection is provided by a guard ring ion implanted with a dose of 10^{13} cm^{-3} of boron. From a technological point of view, they are manufactured with 4H-SiC and 6H-SiC polytypes.

They can replace conventional silicon PN and PIN diodes in conventional power supplies for high power applications, in Power Factor Correction Continuous Conduction Mode (PFC CCM) power supplies called SMPS PWM (Davis et al.,

1991). They are also used in switching and microwave applications. The five largest manufacturers of silicon carbide Schottky diodes are Infineon, APT, Fairchild, Rockwell, CREE. Table 1 shows (see end of article) some Schottky diodes manufacturers with main electrical parameters of their devices (Moussa, 2009). Here few SiC Schottky diodes characteristics:

- Used Metals: Ti, Ni, Au, Pt, Pd,
- Threshold voltage: 1 V to 1.5 V,
- Leakage current: 10^{-10} A to 2.10^{-4} A ,
- Maximum working temperature: 700 $^{\circ}\text{C}$,
- Breakdown voltage: > 1400 V,
- Current density at forward bias: up to 800 A/ cm^2 ,

Figure 4 shows the design profile of a SiC Schottky diode where the 4H-SiC layer is directly grown on a N^+ type 4H-SiC substrate of 0.045 $\Omega\cdot\text{cm}$ resistivity. Schottky contact is obtained by evaporating Ti/Al. The back ohmic contact is obtained by nickel plating followed by an alloy of Ti/Pt / Au on N^+ 4H-SiC substrate (this is known to form good ohmic contacts (Chalabi et al., 2011). Electrical isolation is provided by edge termination passivation with a high resistivity zone achieved with SiO_2 or inert gas ion implantation such as Argon or Neon.

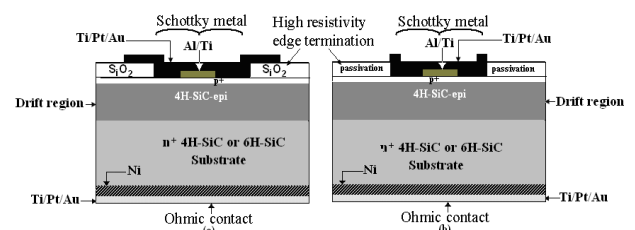


Fig.4: SiC Schottky diode profiles with two high resistivity edge terminations:

(a) SiO_2 (b) ion implantation passivation.

4.2: Bipolar transistors

Silicon carbide is a material used for manufacturing devices intended for high power, high temperature and better performances compared to silicon devices. Research has been focused mainly on MOSFETs, JFETs and MESFETs because of their unipolar properties and high control voltages. Very little research has been done on bipolar junction transistors (BJT) as shown by the number of limited publications. A major reason is short lifetime of minority carriers in p-type semiconductors that negatively affects current gain. However, with quality material and good epitaxial layers, better SiC bipolar junction transistors than field-effect transistors are possible for high currents applications. BJTs from SiC are mostly used as switches since they can withstand high currents compared to field-effect transistors. Its two n regions under the contacts form the main current route, which result in a lowering of initial voltage drop of the switch. Disadvantages of silicon bipolar transistor, in high voltage applications, are Kirk effect and breakdown voltage. Current gain of Si bipolar transistor for high voltage is directly related to a large collector's surface to withstand high voltage and power dissipation. Their current densities are small compared to SiC bipolar transistors with identical dimensions. SiC BJTs have always doping densities twice greater than those of Si BJTs for same voltage (Danielsson et al., 2003). Hence, SiC BJTs are useful high current switching because of low losses, high switching speed and high operating temperatures. They have high breakdown voltages and small ON resistance. To compete with MOSFETs and IGBTs, it is important to increase current gain of BJTs and reduce circuits' power drift. Since SiC

BJTs are exempt of gate oxide, they can have a low ON resistance. In 2005, Danielsson's team achieved a 4H-SiC BJT with a large area working with a current of 30A and a voltage of 1000V whose breakdown voltage is 1100V. Figure 5 shows a cross section of this 4H-SiC BJT (Danielsson et al, 2003)

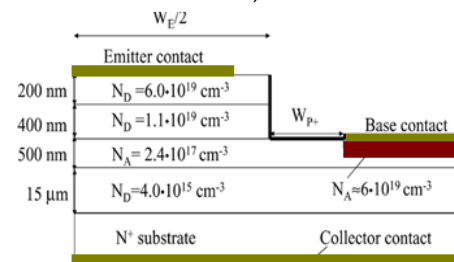


Fig .5: Schematic cross section of 4H-SiC BJTs.

An n-type substrate of low resistivity is used to host an epitaxial collector layer of 15μm thickness doped with 4.10^{15}cm^{-3} nitrogen atoms. A large area enables the device to withstand high power. Epitaxial growth of base and emitter is done without interruption to avoid defects formation at their interface and thus avoid interfacial recombination and increase device power gain. The base is very narrow (400 nm) to prevent recombination and is doped with $2.4 \cdot 10^{17}\text{cm}^{-3}$ Aluminum atoms. The emitter is composed of two layers doped with nitrogen. The first layer of 400μm thickness has a $1.1 \cdot 10^{19}\text{cm}^{-3}$ doping and the second layer of 200μm thickness has a 6.10^{19}cm^{-3} doping. This last layer of emitter and N⁺ doped substrate promote ohmic contacts that connect emitter and collector to outside world. For the same purpose, a 6.10^{19}cm^{-3} doped layer is deposited on the base layer. Figure 6 shows transistor collector current I_C variation with collector-emitter voltage V_{CE} at room temperature. For $I_B = 1.5\text{mA}$ and V_{CE} greater than 7.5V, I_C current decreases due to base large surface contact.

I_C collector current for I_B values of 0.5mA and 1mA remains constant when V_{CE} varies from 6V to 600V. Figure 6 also shows breakdown voltage BV_{CE0} which is about 1100V. This transistor has a current gain β of 64 for an emitter length $L_E = 30\mu m$. The gain β varies with emitter length L_E and base width W_E as shown in Figure 7. This good result of gain β is attributed to an improved design of base and emitter layers and continuous epitaxial growth of base-emitter junction.

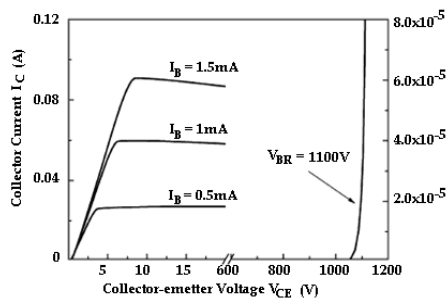


Fig. 6: Measured I_C versus V_{CE} including breakdown voltage BV_{CE0} for a BJT with $W_E = 20 \mu m$, $L_E = 1.13 mm$

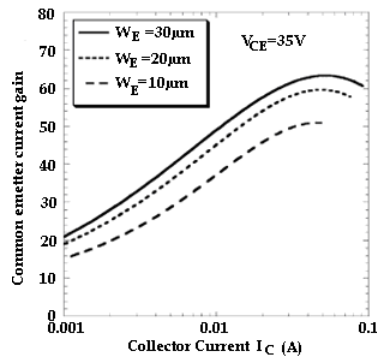


Fig. 7: Measured common emitter current gain β for 3 emitter widths values

The transistor shown in figure 8 is designed for RF power applications (Perez-Wurfl et al, 2003). It consists of a $3 \mu m$ thick collector with $2.10^{16}cm^{-3}$ doping, a base layer thickness of 100nm with $2.10^{18}cm^{-3}$ doping and an emitter with a 150nm thickness with $1.10^{19} cm^{-3}$ doping. This 4H-SiC transistor is formed of epitaxial layers on a 4H-SiC n-

type substrate of $0.016 \Omega.cm$ resistivity to achieve ohmic contact to the collector. This structure is identical in form to that of Figure 5.

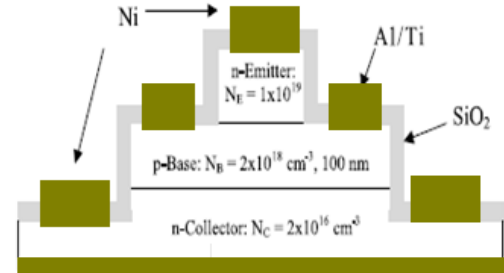


Fig. 8: Structure of a 4H-SiC BJT

Figure 9 and 10 show I-V characteristics at low and high current of this 4H-SiC transistor. The voltage-offset is about 4V due to poor contact and a high sheet resistance related to an incomplete carrier's activation of acceptors in the p-type layer of very narrow base (100nm). The effect of non saturation is very important even at low current which means leakage currents due to soft base-collector junction breakdown with high conductance. For strong currents and from $V_{CE} = 30V$, collector current decreases with increasing V_{CE} . This becomes so pronounced when current I_B increases (Perez-Wurfl et al, 2003).

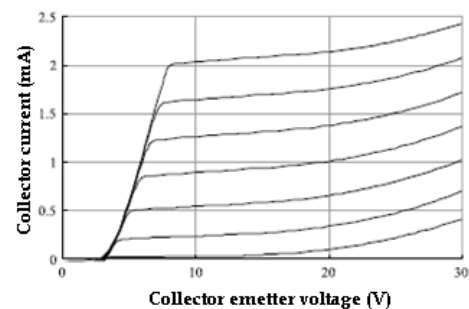


Fig. 9: Collector-Emitter characteristics at low current

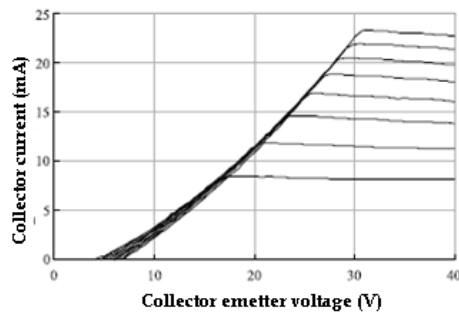


Fig. 10: Collector-Emitter characteristics at strong current

4.3: Field-effect transistor

Since the seventies, Muench et al. have fabricated MOSFETs, JFETs, and BJTs (Muench et al, 1977). In 1984 Sasaki (Sasaki et al, 1984) showed that devices from 3C-SiC have greater mobility than those from 6H-SiC mainly at high temperature. At the time there was a great difficulty to grow a 6H-SiC epitaxial layer on a 6H-SiC substrate, silicon or any other substrate whether by Liquid Phase Epitaxy (LPE) or Chemical Vapor Deposition (CVD). However, it was proved that one could obtain a 3C-SiC single crystal by epitaxial growth on a silicon substrate using CVD at 1330 °C (Ekoué, 2002). We show in this study a MOSFET structure and another CMOS-SOI. (Thesis Chalabi D. 2005)

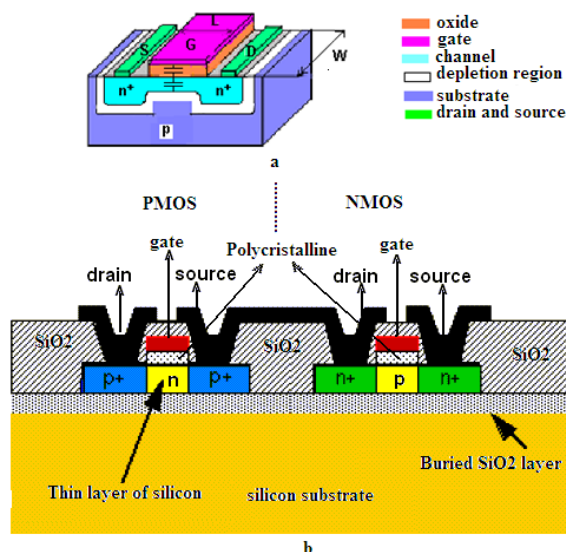


Fig. 11: Structures of field-effect transistors: a) bulk MOS, b) SOI CMOS technology.

Yoshida [Yoshida et al, 1986] has achieved the growth of p-type and n-type 3C-SiC MESFETs on silicon substrates. Schottky and ohmic contacts were made of Au and Al, respectively. His devices had very important leakage currents of the same magnitude as drain, Figure 12. This was highlighted by biasing the MESFET with gate voltages above 0.6V. It is quite possible that there was contamination of the process during epitaxial growth of layers. The channel resistance is large too.

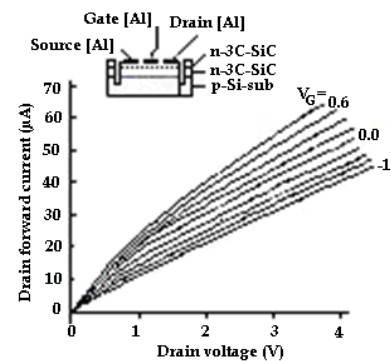


Fig.12: 3C-SiC MESFET transistor $I_D(V_{DS})$ characteristics with current leakage

Figure 13 shows I-V characteristics of the same transistor after eliminating leakage current by biasing the grid with voltages lower than 0.6V.

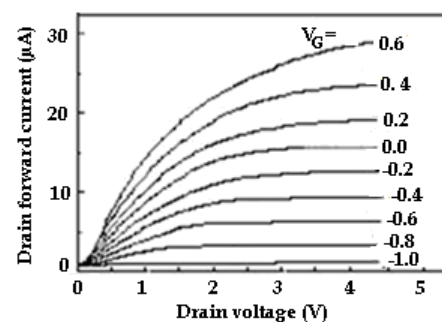


Fig.13: 3C-SiC MESFET transistor $I_D(V_{DS})$ characteristics without current leakage

Just few years later, with progress in the field of epitaxial growth, it was possible to grow and obtain 6H-SiC single crystals on 6H-SiC substrates to allow the manufacture of devices for optoelectronics, power electronics, and high temperature and high frequency applications (Madelun,1996 ; Planes,1999 ; Committee on Materials for High-Temperature,1995 ; Planes, 1999) Even memories that were the exclusive domain of silicon have been obtained (Edmond et al, 1993 ; Palmour et al, 1993) . The 6H-SiC with its 3.02 eV wide bandgap and its 4.10^6V/cm breakdown electric field enabled the fabrication of LEDs emitting in the blue. Quantum yield was however low (0.03%) for a current of 10A at a voltage of 3V. For high temperatures, under the needs expressed in military, aerospace, automobile, etc. for devices, technological progress led to the production of devices operating at temperatures above 923K [Palmour et al, 1993 ; Sasaki et al, 1984) with excellent output characteristics, Figure 14. The later were obtained on the 6H-SiC MOSFET of Figure 15.

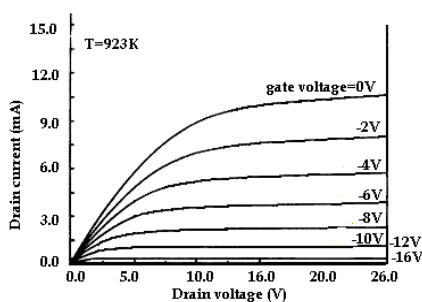


Fig.14: 6H-SiC MOSFET transistor $I_D(V_{DS})$ characteristics at 923K

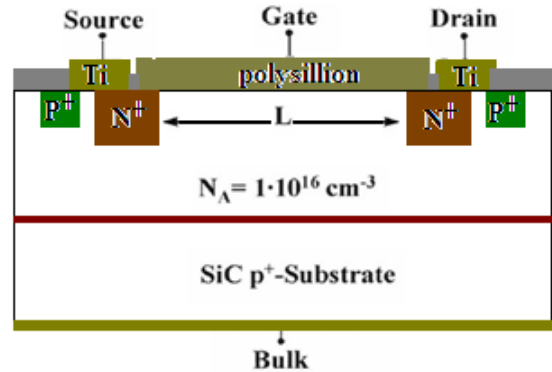


Fig. 15: Cross-section of n-channel inversion MOSFET

N^+ drain and source regions are doped by ion implantation of nitrogen and external contacts are made with aluminum. The grid is made with a polycrystalline layer doped by ion implanting phosphorus and deposited on a layer of SiO_2 obtained by LPCVD. Two P^+ protecting areas are also obtained by implantation and covered by an oxide layer deposited by CVD. Current and transconductance g of MOSFET increase with temperature, Figures 16, 17 and 18 (Schmid et al., 1999), while threshold voltage V_T decreases, Figure 19, 20 and 21 (Hasanuzzaman et al, 2004; Schmid et al, 1999)

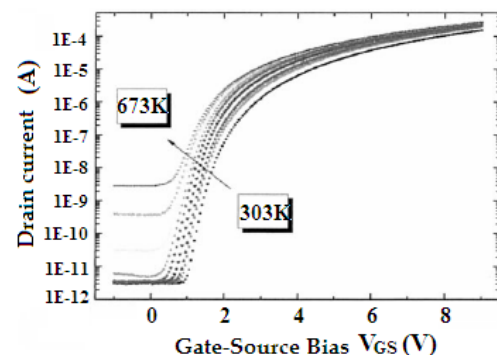


Fig.16: MOSFET transfer characteristics dependence on temperature ($W/L=100/20$)

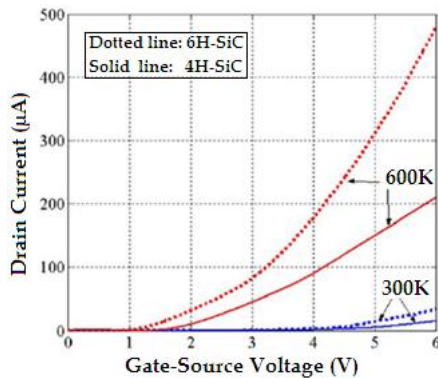


Fig.17: Transfer characteristics of 4H- and 6H-SiC lateral MOSFET

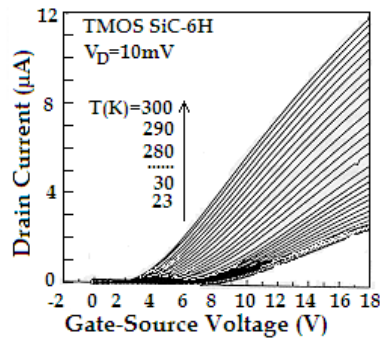


Fig.18: Effect of temperature on conductivity and threshold voltage of 6H-SiC MOSFET

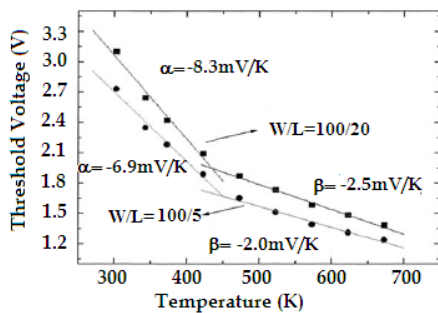


Fig.19: Threshold voltage versus temperature

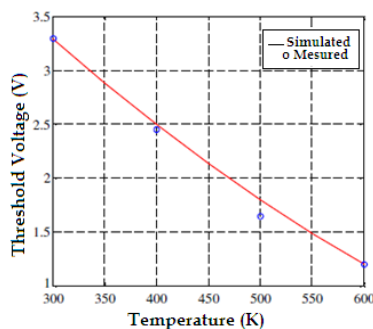


Fig.20: Simulated and measured threshold voltage with temperature

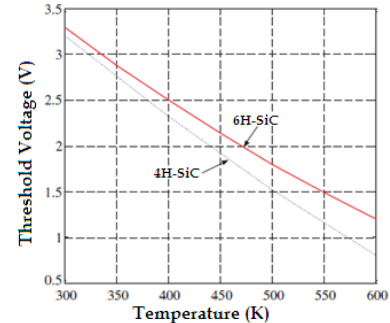


Fig.21: Threshold voltage temperature variation of two 4H- and 6H-SiC lateral MOSFET

As shown in Figure 22, conductivity increases with temperature in the range 23 to 300k (Bano, 1997). Temperature promotes the effect of none saturation when it exceeds a certain critical value, Figure 23.

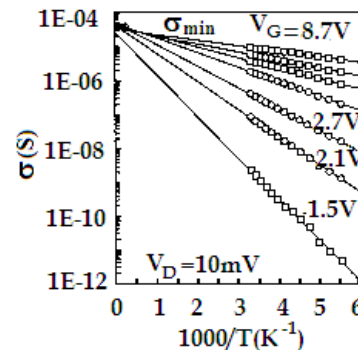
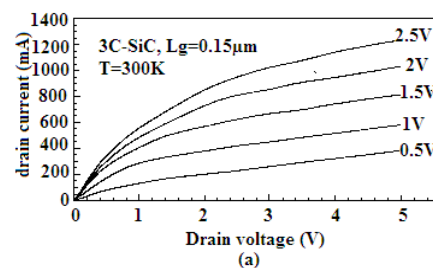


Fig.22: Conductivity variation with temperature



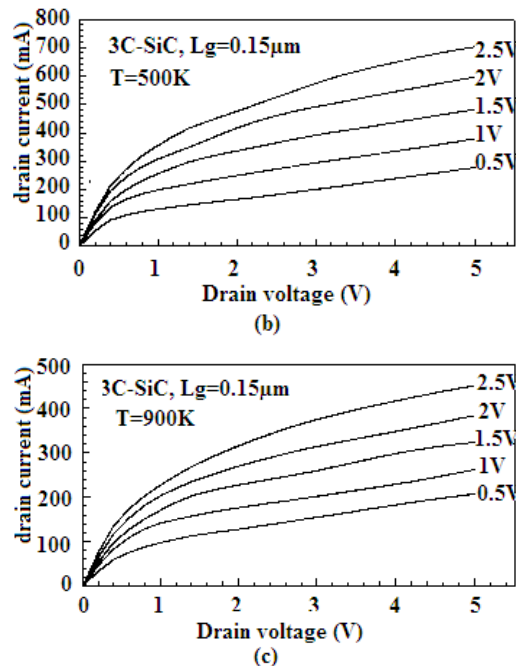


Fig.23: 3C-SiC MOSFET transistor $I_D(V_{DS})$ characteristics at (a) 300K , (b) 500K and (c) 900K

All current-voltage characteristics as a function of temperature show the same aspect: evidence of absence of saturation, Figure 23. In this case, the device has a continuous decrease of current as a function of temperature. for a 5V V_{DS} voltage and a gate voltage of 2.5V, currents of 1200mA, 700mA and 440mA for temperatures of 300k, 500k and 900k, respectively, have been measured. Davis et al (Davis et al, 1991) have shown that for MOSFETs, obtained from β -SiC (111) on the 6H-SiC, current increases with temperature until a certain critical value of temperature between 550°C and 650°C and then decreases. In a study by Bano (Bano,1997), the same observation was made for temperatures between 23k and 300k, Figure 18. Similarly, we found currents of 16 mA, 18mA and 11mA respectively for temperatures of 296k, 573k and 923k for a V_{DS} voltage of 25V and a zero gate voltage, Figure 24. For 6H-SiC MESFETs, current

decreases continuously as a function of temperature and so does its threshold voltage.

For some silicon carbide devices, current versus temperature reaches a maximum and then decreases since though SiC is a semiconductor, its crystallography and interface problems (disorderly interface) make behave differently from conventional semiconductors. Such current behavior, which is related to conductivity variation with temperature, is not well understood because crystal orientations, type of SiC, component design, doping, oxidation are all different from one device to the other. For previous reasons, conductivity maximum value is reached between 503K and 923K. In a solid because of the bonding forces between atoms, thermal agitation happens according to vibration modes of whole structure. Difficulty of moving carriers comes from interaction between waves associated with carriers and waves associated with crystal vibration. When temperature rises, number of vibration modes increases, increasing probability of interaction leading to a reduced mobility and therefore flow (mahmoud, 2001). This occurs for silicon, germanium and gallium arsenide at relatively low temperatures. SiC-SiO₂ interface is the key in understanding high temperature effect in silicon carbide devices. Brown et al (Brown et al, (199) have shown that impurity atoms are introduced at that interface which encourages dangling bonds formation that act as are trap centers. Conductivity as a function of temperature is directly proportional to mobility ($\sigma(T) = q \mu n$). When temperature increases beyond 623k, carriers-phonons collisions lead to a mobility decrease and therefore a decrease.

in current and transconductance g_m . The decay of the latter causes a decrease in devices cutoff frequency (Mahmoud, 2001). Leakage currents for high temperatures become very low. Similarly, the current due to impact ionization at high drain voltage is greatly reduced [Bano,1997]

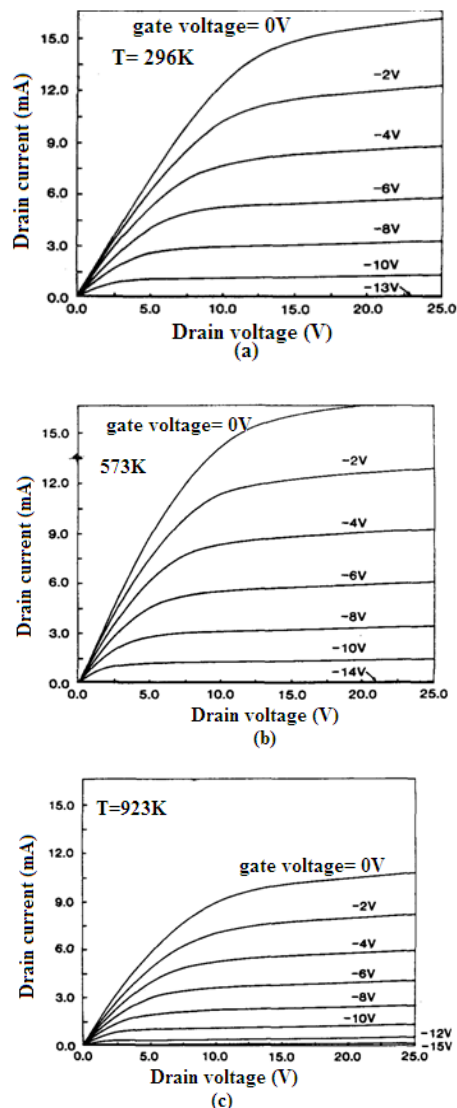


Fig.24: 3C-SiC MOSFET $I_D = f(V_{DS})$ characteristics for $L_g = 0.15\text{mm}$ at 296K, 573K and 923K

The threshold voltage is not and will not be determined as in the case of conventional MOS structures, because it is not the surface potential $2\phi_F$. We define threshold

voltage as the value of gate bias which allows the formation of channel at the interface and not that which increases the depletion zone.

In the case of a conventional MOS, it is obtained from voltage extrapolation of $I_D(V_G)$ characteristic or from C-V curve. Thus from measurements on the conductance, transport is thermally activated in the temperature range cited above (Bano, 1997 and Palmour et al, 1993). The generation-recombination current dominates at temperatures below 200°C , while diffusion current dominates at temperatures above 200°C . Of course this is for specific devices.

In the field of power and high frequency, it has been demonstrated Palmour et al, 1993). that 6H-SiC transistors deliver a 65W power for radio frequencies and can operate at frequencies up to 10GHz with a power density of 4W/mm.

5: Conclusion

This study focuses on the properties and applications of MOSFETs, MESFETs, BJTs and diodes based on silicon carbide materials. The physical characteristics of this material are the base of many devices with improved performance in both frequency and power. Its good performance in harsh atmospheres made of silicon carbide, a very promising material for electronic technologies in the field of aerospace, on board systems, automotive, nuclear power plants, industry, radar, etc. Our study was mainly about the effect of temperature on parameters such as conductivity, transconductance and cutoff frequency. For some devices, conductivity increases with temperature until a certain critical value then it decreases. For other devices, conductivity and transconductance

decrease with temperature like a classical semiconductor. This phenomenon depends on the substrate polytype, doping, oxide, type of metal contacts and so on.

6 : Reference

- Moussa, R. (2008). :Thèse de doctorat INSA Lyon
- Chalabi, D. ; Saïdane, A ; Abdelaoui, M.; Benzohra-Idrissi, M; Benzohra, M. & Ketata, M, (2011) (to appear in Microelectronics reliability)
- SZE, S.M. (1981). Physics of Semiconductor Devices. John Wiley & Sons.
- Milnes, A.G. & Feneht, D.L. (1972). Heterojunctions Metal-Semiconductors Junctions Academic. Press New York and London.
- Rhoderick, E.H. (1972) IEE. Vol 129 n°1
- Wu, C.Y (1982) . J. Applied Phy. Vol 53 n° 8 p.5947
- Crowel, C.R & SZE, S.M. (1966). Solid State Electronic vol. 9 p.1035.
- Shannon, J.M.. (1976). Solid State electronic vol.19.n°6, p.537.
- Shannon, J.M. (1977). Solid State electronic vol.20. p.869.
- Ragunathan, R. & Baliga, B.J. (1998) P-Type 4H and 6H-SiC High-Voltage Schottky Barrier Diodes: IEEE Electron device letters, Vol. 19, N°3.
- Chalabi, D. (1985) Thèse docteur ingénieur INPT Toulouse (France).
- Atindal, S ; Karadeniz, S ; Tugluoglu, N. & Tataroglu, A. (2003). 'The role of interface states and series resistance on the I-V and C-V characteristics in Al/SnO₂/P-Si Schottky diodes'. Solid State Electronics vol 47 p.1847-1854.
- Padovani, F.A. (1970) J. Applied Physics . Vol 37, p. 921
- Sochacki, M; Szmidt, J; Bakowski M; & Werbowy, A..(2002) Influence of annealing on reverse current of 4H-SiC Schottky diodes. Diamond and Related Materials 11 1263-1267
- Danielsson, E,* , Zetterling, M; Domeij, M; Östling, M; Forsberg, U & Janzén, E. (2003). Investigation of thermal properties in fabricated 4H-SiC high power bipolar transistors Solid-State Electronics 47 639–644]
- Perez-Wurfl, I; Krutsinger, R; , J.T. Torvik, J.T & Zeghbroeck, B.V. (2003) : 4H-SiC bipolar junction transistor with high current and power density : Solid-State Electronics 47 229–231
- K. Sasaki, K; Sakuma, E; Yoshida, S & Gonda, S. (1984) Appl. Phys. Lett. 45, pp 72,
- Thesis Chalabi D. 2005
- S. Zaima, S.; Onada, K; Koide, Y. & Yasuda, Y. (1990) J.Appl. Phys. 68 n°12 pp 6304
- Shibahara, K; Saito, T; Nishino, S & Matsunami, H. (1986). IEEE Elect Dev Lett. 12 pp 692
- S.Nishino, S; H. Suhara, H; Ono, H & Matsunami, H. (1987) J.Appl. Phys. 61 pp :4889
- Zaima, S; Onada, K; Koide, Y; & Yasuda, Y (1990). J.Appl. Phys. 68 n°12 pp 6304
- Palmour, J.W ; Edmond, J.A; Kong, H.S & Carter, C.H. (1993) , Physica B 185 pp :461
- Edmond, J.A; Kong, J.A & Carter Jr. C.H. (1993). Physica B 185 pp :443
- D.M. Brown, D.M; Ghezzi, M; Kretschmer, J; Downey, E.,; Pimbley, J & Palmour, J.W. (1994). SiC MOS interface characteristics. IEEE Trans. Electron Devices, 41, issue 4. pp 618-620
- Schmid, U; Sheppard, S.T; Wondrak, W & Niemann, E. (1999). :Electrical characterization of 6H-SiC enhancement-mode MOSFETs at high temperatures : Materials Science and Engineering B61–62 pp 493–496



Hasanuzzaman, Md; Islam, S.K; Tolbert, L.M & Alam, M.T. (2004): Temperature dependency of MOSFET device

characteristics in 4H- and 6H-silicon carbide (SiC): Solid-State Electronics 48 1877–18

Table 1: Main Schottky diodes manufacturers (Moussa, 2009)

Manufacturers	Breakdown voltage (V)	Forward current (A)	Forward voltage (V)	Leakage current (μA)
Microsemi	200	1 to 4	1.6 to 1.8	20 to 50
	400	1 to 4	1.6 to 1.8	20 to 50
	600	1 to 4	1.6 to 1.8	20 to 50
CREE	300	1 to 20	1.2 to 1.4	50 to 200
	600	1 to 20	1.5 to 1.8	20 to 200
	1200	5 to 20	1.6 to 1.8	10 to 200
	1200	20	-	-
Infineon	300	10 to 20	1.5 to 1.7	15 to 200
	600	2 to 16	1.5 to 1.7	2 to 200
APT	600	20	-	-
ROHS	1200	5 to 30	-	-
	1200	10 to 20	-	-
ERIS	20 to 200	1 to 16		
	20 to 200	1 to 60		
STM microelectronics	600	8	-	-
	600	10	-	-