RESEARCHES ON APPLICATIONS FOR SILICON CARBIDE

Constantin STANESCU, Cristiana VOICAN
Politehnica University of Bucharest, Romania
Electronic College of Bucharest, Romania
E-mail: prof_cstanescu@yahoo.com, voicancristiana@yahoo.com

KEYWORDS: Silicon, carbide, semiconductor.

ABSTRACT. Although the excellent physical and electronic properties of silicon carbide (SiC) have been known for many years, its commercialization as a semiconductor has been severely limited until recently by the lack of large single crystal substrates of SiC suitable for devices fabrication .However, Cree Research has developed a process for producing SiC substrates and is currently in production of 35 mm diameter wafers and will be at 50 mm diameter by mid -1994.The first high volume commercial product from SiC is a blue light emitting diode (LED).As a result of these developments, SiC is receiving increased attention because of its potential for short wavelength optoelectronic devices ,high temperature devices, high voltage power conditioning electronics ,and high power microwave devices.

1. INTRODUCTION

Silicon carbide possesses a unique combination of properties which are not available from other more common semiconductor materials. As such, it is being examinated throughout the world for employment in high temperature, high frequency and high power electronic devices, as well as blue LEDs, UV photodiodes and for radiation and electromagnetic pulse (EMP) resistant electronics. Since its accidental synthesis during attempts to produce synthetic diamond in the late 1800's,SiC has fascinated crystallographers as the archetypal polytypic material. Silicon carbide is the only compound species that exists in the solid state in the Si-C system and can occur in the cubic (C),hexagonal (H), or rhombohedral (R) structures. Silicon carbide is known to form over 170 crystal structures which are created by varying the stacking sequence of the closest packing plane. There is only one cubic SiC polytype, commonly referred to as beta silicon carbide (ß- SiC).All of the other non-cubic (hexagonal and rhombohedral) polytypes are referred to collectively as alpha silicon carbide (a- SiC).The most widely used notation for the polytypes of SiC is the Ramsdell notation which gives the number of layers in the unit cell and denotes the structure (cubic, hexagonal or rhombohedral) by a letter. In this notation the cubic form of SiC is referred to as 3C-SiC (3 layers and cubic structure).The two polytypes discussed herein are 4H- and 6H-SiC.They are the only polytypes which are commercially available as single crystalline substrates and both have hexagonal structures with 4 layers (4H-SiC) or 6 layers (6H-SiC) in their unit cells.

2. TECHNICAL CHARACTERISTICS OF SILICON CARBIDE

The process used to process the single crystal boules from which the substrates (wafers)are cut is a seeded sublimation process and is described elsewhere .Cree is currently in production with 35 mm diameter 6H-SiC wafers

and 30 mm diameter
4H-SiC wafers .The wafers can be doped either p-type with aluminum or n-type with nitrogen.

Wafers 50 mm in diameter are being grown in R&D currently and will be in production by mid-1994 for 6H.These wafers currently have a total etch pit density of 1-2 $x10^4$ cm^{-2}. Silicon carbide wafers have traditionally had high densities (400-500 cm^{-2}) of micropipe defects which can kill an electronic device. Recent wafers have micropipe densities as low as 55 cm^{-2}.

The primary application for SiC wafers is as a substrate for homoepitaxial growth of SiC structures for fabrication of a wide variety of electronic and optoelectronic devices.

Epitaxial layers of 6H-SiC can be grown and doped either p-type or n-type to carrier concentrations in the range of 5 $x10^{14}$ cm^{-3} to>1 x 10^{20} cm^{-3}.In addition ,ohmic contacts with specific contact resistivities as low as $10^{-5}$$Ocm^2$ can be achieved for both n- and p-type material. Silicon carbide also has a native oxide (SiO_2) which can be thermally grown [6] for surface passivation, as a gate insulator or anti-reflective surface. Dry etching processes have been developed which allow etching of mesa structures in SiC. Processes for ion implantation and Schottky contact formation have also been developed for SiC. These fundamental processing steps supply the building blocks required for fabricating SiC devices.

The excellent physical and electronic property of SiC allows the production of electronic devices that can operate at higher temperatures and power levels than devices produced from Si or GaAs. These properties include a wide bandgab (E_g =3.0eV for 6H and 3.26 eV for 4H), high electric breakdown field of 4 x 10^6 V/cm, and high thermal conductivity of 4.9 W/cm-K. The breakdown electric field of SiC is > 10 times that of Si or GaAs and its room temperature thermal conductivity is higher than that of copper. The high saturated electron drift velocity of 2.0 x 10^7 cm/sec also indicates that SiC has great potential for high power, high frequency operation. The wide E_g of this material greatly reduces the thermal generation of minority carriers at room temperature in comparation with Si, giving the potential for 6H-SiC random access memory (RAM)that holds its charge indefinitely .Additionally ,the wide E_g allows for unique optoelectronic properties ,including blue light emitting diodes (LEDs) emitting in the 2.6 eV energy range and photodiodes having a peak response in the ultraviolet (UV)range. The availability of high quality, relatively large wafers of SiC also provides the opportunity to improve thin film grown of other wide handgap materials that are nearly lattice matched to SiC which are not available in single crystalline wafer from. Some of the recent device results for each application area (optoelectronic devices, high temperature device, high power / high frequency devices, and nonvolatile memory) will be discussed, along with some specific applications.

3. OPTOELECTRONIC APPLICATIONS

The two primary optoelectronic 6H-SiC devices are blue LEDs and UV photodiodes. Blue LEDs are by far the most established market for 6H-SiC devices to date.

Most of the major applications for blue LEDs involve combining them with commonly available GAP-based red and green LEDs to produce full color displays. By mixing red, green and blue light, any color in the visible spectrum may be obtained. This is of particular interest to the manufactures of LED-based displays that are used for both commercial signs and full color LED monitors. Blue LEDs are also being introduced into a variety of full color photographic slide scanners and film exposure systems. Other applications are for discrete blue LED indicators for instrumentation and consumer electronics.

Blue LEDs fabricated in 6H-SiC utilize a donor-acceptor pair recombination in an epitaxial layer containing both Al and N dopants. The transition causes photon emission with a peak wavelength of about 470 nm, which is in the deep blue spectrum. The blue LEDs manufactured by Cree Research have radiant flux values as high as 18.3 µW at 20 mA (V=3.0V), corresponding to an external quantum efficiency of 0.03%.By operating at the maximum rated current of 50 mA, a radiant flux of 36 µW is achieved.

Photodetectors fabricated in 6H-SiC show peak quantum efficiencies in the range from 250-280 nm. Quantum efficiencies of nearly 100% have been measured .In addition to the very high efficiencies ,the extremely low leakage currents measured on 6H-SiC pn junctions (10^4-10^5 times less leakage than Si junctions) allow a sensitivity more than 10.000 times higher than common Si-based UV photodiodes. Figure 1 shows responsivity vs. wavelength as a function of temperature for Cree's 6H-SiC UV photodiode. Figure 2 shows the dark current density as functions of reverse voltage and inverse temperature for this device.

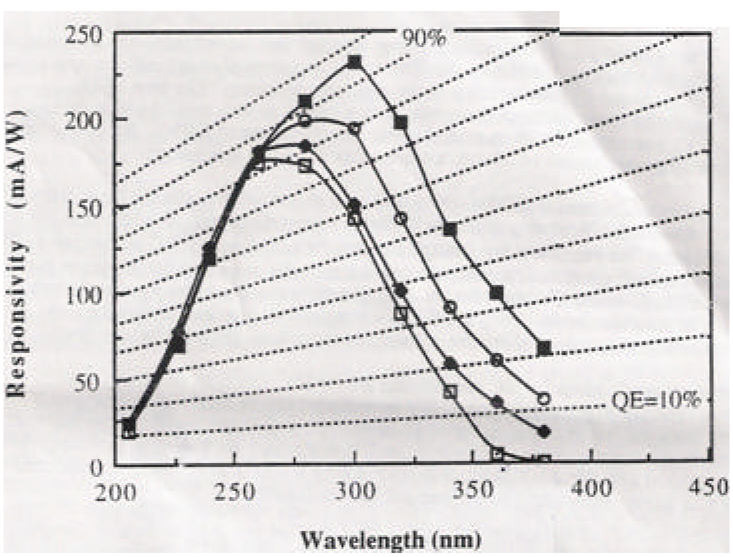

Fig.1. Effect of measurement temperature on the UV response of 6H-SiC photodetectors. The temperatures tested were: (?) 223K, (?) 300K,(?) 498 Kand ,(¦)623 K.

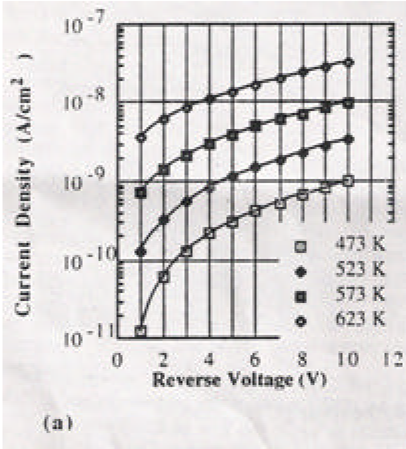

Fig.2 . a. Logarithmic dark-current density versus reverse voltage for 6H-SiC UV photodetectors.

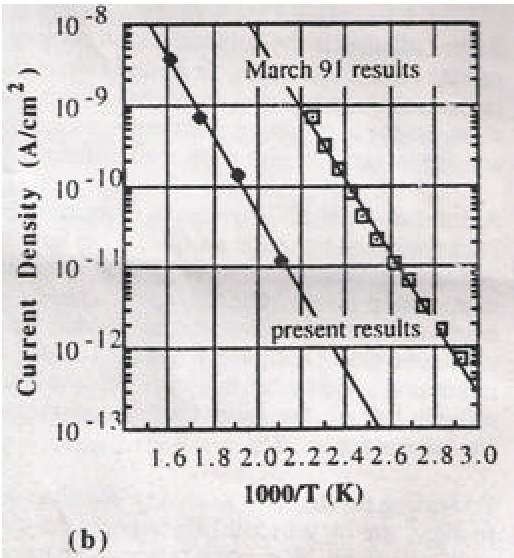

Fig.2 . b . Logarithmic dark-current density versus inverse temperature for 6H-SiC UV photodetectors.

The primary applications for SiC photodiodes are for UV detection, dosimetry, and analysis .Specifically, the detection of UV from flames can be used for applications ranging from solide-state detection for combustion control to detection of missile plumes. Dosimetry applications range from solid-state UV monitoring for industrial processes (UV curing,etc.) to a personal UV detector for monitoring sun exposure . Analysis applications include air quality monitoring equipment and UV spectroscopy.

REFERENCES

[1] L.Chang, T.S. Lin and J.L.Chen, Appl.Phys.Lett., 62, (26) , 3444, (1993).
[2] J.A.Cooper, Jr., M.R.Melloch, W.Xie, J.W.Palmour and C.H.Carter, Jr., presented at the International Conference on Silicon Carbide and Related Materials '93, November 3, 1993 in Washington, DC.
[3] J.A.Edmond, H.S.Kong and C.H. Carter, Jr., Physica B, 185, 453, (1993).
[4] G.Kelner, S.Binari, M.Shur and J.Palmour, Electron. Lett., 27, 1038, (1990).
[5] M.E.Li.n, B.Sverdlov, G.L.Zhou and H.Morkoc, Appl.Phys.Lett., 62, (26), 3479, (1993).
[6] J.W.Palmour, H.J.Kim and R.F.Davis. Materials Research Society Symposium Proceedings Vol.54,MRS, Pittsburgh, PA, 1986, p.553.
[7] R.J.trew, J.B.Yan, and P.M.Mock, Proceedings of the IEEE, 79, 598, (1991).
[8] Voican Cristiana , Performances of the small Compressors in Refrigeration Industry, Oradea,mai,2002.
[9] Voican Cristiana , Applications of the the small Compressors, Oradea, mai, 2002.