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Electrical characterization of p-type 4H- Silicon carbide metal contacts

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ABSTRACT

Silicon Carbide (SiC) is very important subject for the industrial applications. It has wide band gap structure, so it can be used for high power or high frequency applications. This work concentrates in using gold (Au) and chromium (Cr) as metal contact on single crystal silicon carbide(4H-SiC) . This type of SiC showed low mobility anisotropy , but high electron mobility. Thermal evaporation has been used to deposit gold or chromium metals with purity of 99.99% on top of the SiC wafer to form a contact area . The contact area had diameter ranging from 1 to 2 mm. The electrical measurements of the junction were obtained, and used to characterize the current -voltage behavior as well as capacitance-voltage. These measurements were enabling us to study the barrier height doping concentration, as well as the deep levels of the device near the surface.

Key words : P-type-SiC, metal-semiconductor contacts, electrical measurements.

INTRODUCTION

Silicon carbide

Silicon carbide (SiC) has attracted interest in recent years as a promising wide band gap semiconductor. It enjoys unique properties that make it a candidate to become useful in power devices. For example, SiC has an order of magnitude higher breakdown electric field (2-4×10^6 V/cm) than the conventional materials, and an electric mobility only ~ 20% lower than that in Si [1-3], The higher breakdown electric field allows the design of SiC power diode with ten times thinner and hundred times high doping than Si diode[4] . In spite of the great advance in material preparation, SiC still suffers from elementary screw dislocation [6] and micropipe defect [5]. The effect of these defects on the reverse characteristics is well known as they degrade the breakdown voltage. The effect on the forward voltage drop still needs more elaborate study. The use of conventional semiconductors such as silicon (Si), and germanium (Ge) are limited in high voltage devices. The high voltage devices from these materials require more width and less doping concentration, which give more specific on resistance[4], and consequently, generate more heat and thus complicate the problem. Further, Si-based high voltage devices are limited in there operating capability to 150°C[7]. These reasons drive the scientists to research about new material having more capability in high voltage, and high temperature applications.

Crystal structure of silicon carbide

SiC is polytypic semiconductor. There are more than 170 polytypes of SiC [8]. The cubic polytype is called β-SiC while all other polytypic structures are denoted by α-SiC. All crystal structures of different polytypes have the same building unit. The building unit is a plane of Si atoms over a plane of C atoms. The most common way of designating the various structures is the Ramsedell notation. This notation consists of a number followed by a letter. The number satisfies the number of double

layers in stacking repeated sequence, and the letter designates the crystal structure. The more common SiC poletypes, their crystal structures, and stacking sequence are listed in Table 1. For example when we say 3C it means that there are three repeated stacking double layer (ABC/ABC), the letter C means that the crystal structure is cubic[9].

Growth of silicon carbide crystal

Reproducible process for producing the single crystal SiC was the cumber of development devices fabricated from it for many decades[10]. More researches were toward to development this processes. There are many methods to grow SiC single crystal such as hetero epitaxial growth, physical vapor transport, and epitaxial growth [11].

Table 1: Selected SiC polytypes[9].

Remsdell Notation	Crystal Structure	Stacking Sequence
3C	Cubic	ABC/ABC
4H	Hexagonal	ABAC/ABAC
6H	Hexagonal	ABCACB/ ABCACB/
2H	Hexagonal	AB/AB

Metal semiconductor contacts

The energy band structure of the Schottky effecting for a metal semiconductor contact shown in Fig. 1[12] .The built-in potential is given by:

$$V_{bi} = \varphi_{bn} - V_n \qquad ...(1)$$

Where ϕ_{bn} is the barrier height of a metal-semiconductor contact and V_n is the potential difference between the Fermi level and the bottom of the conduction band, this can be written as[12].

$$V_n = \frac{kT}{q} \ln \frac{N_C}{N_A} \qquad ...(2)$$

In the following our study will be consideration in p-type semiconductor, it has been known of this type of device .The depletion layer can be formulated as:

$$W = \sqrt{\frac{2\varepsilon_S}{qN_A}\left(V_{bi} - V - \frac{kT}{q}\right)} \qquad ...(3)$$

Also the junction capacitance C can be defined as.

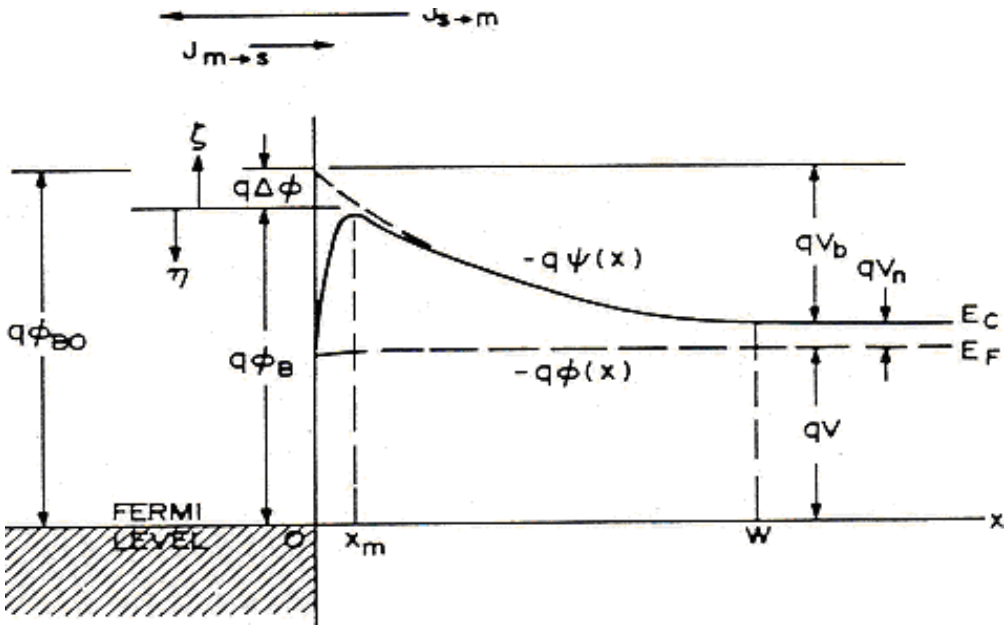

Fig.1: Energy band diagram incorporating Schottky barrier lowering[12].

$$C = \frac{\partial Q}{\partial V} \quad ...(4)$$

Where Q:

$$Q = qWAN_A \quad ...(5)$$

Now since C:

$$C = \frac{\varepsilon_S A}{W} \quad ...(6)$$

Then resulting as[15] :

$$\frac{1}{C^2} = \frac{2}{q\varepsilon_S N_A A^2}\left(V_{bi} - V - \frac{kT}{q}\right) \quad ...(7)$$

The current-voltage characteristics of a Schottky barrier are given by :

$$I = I_S\left[\exp\left(\frac{qV}{nkT} - 1\right)\right] \quad ...(8)$$

Where :

$$I_S = AR^*T^2 \exp\left(-\frac{q\varphi_B}{kT}\right) \quad ...(9)$$

Due to image force induced will lower the potential energy when the electric field is applied according the barrier height will be lowered and this expression by the following.

$$\Delta\phi\sqrt{\frac{qE_{max}}{4\pi\varepsilon_S}} \quad ...(10)$$

EXPERIMENTAL

Preparation contacts

After cleaning the SiC surface by using Huang chemical method[13]. Edward 306 vacuum coating unit was used for depositing the metal (Au or Cr) on the top of SiC surface. This coating unit has two vacuum stages (mechanical and diffusion pumps) with gages, penning and pirani to measure the pressure inside the bell jar. A molybdenum (Mo) boat was used as source which heated by a dc-current ranging from 60 to 80 Ampere.

A movable shatter was placed between vapor source and substrate (SiC). A luminum mask with holes of 1 to 2 mm diameter attached to the substrate to form the selected area. Especial arrangements inside the bell jar was adopted to maintained low pressure (10^{-5} Toor) , the boat is fixed between filament holder and filled by metal with adjustable distance to grow the film with suitable evaporation rate . The SiC wafer is placed on the mask and fixed about 20 cm above the boat.

Capacitance-voltage measurements

Two terminals methods were used , silver film evaporated on the back surface of the wafer to form one contact where the other terminal connected to the metal contact on the top of the wafer and then connected to the C-V equipments. Measurements had been taken at room temperature, the relationship between $1/c^2$ and voltage has been studied. From these measurements the doping concentrations as well as the built-in potential were obtained, also the top of the valance band and the Fermi level qv_p can be determined.

Fig. 2 and Fig. 3 were followed the depletion layer capacitance theory of Schottky barrier[15]. Different diode sizes on the same wafer showed the effective of the area to give different capacitance for the same applied voltage. This can be seen by the existing of different slope in the mention figures. However the effective of the different area of the capacitance will not effect the uniformity of the doping concentration across the device[12].

From Fig. 2 and 3 the value of N_A can be calculated as follows.

Table 2: Summery of the results.

P-type - 4H SiC metal contacts	
Wafer Thickness (μm)	380
Resistivity ρ (Ω.cm)	1.28
Mobility (cm^2/V.s)	120
Doping concentration (cm^{-3})	4×10^{16}
V_p (eV) (Refer to Fig. 1 and equ. 2)	0.18
Built-in voltageV_{bi} Au contact(V)	1.9
Built-in voltage V_{bi} Cr contact(V)	2.4
Barrier height of Au contact (eV)	2.08
Barrier height of Cr contact (eV)	2.58

$$NA = \frac{2}{q\varepsilon_S A^2}\left[\frac{d(1/C^2)}{dV}\right]^{-1} \quad ...(11)$$

Where ε_s = 9.7 ε_o, and A is the effective area of the diode. This area varies from one diode to the other, but it not major influence on the performance of the device .However the doping concentration can be calculated by using the following .This can be seen from Table 2[14,15].

$$\rho = \frac{1}{q\mu N_A} \quad ...(12)$$

Current-voltage measurements

Hp system 4140B Pico Amber meter and DC-Voltage as well as vacuum furnace type VT 5042 EKP. have been used .Fig. 4 showed I-V characteristic at different temperatures .Chromium (Cr) contacts has been deposited to the SiC and the I-V showed the non linear behavior. The turn on voltage tend to decrease slightly, this is because the back contact which made of silver is not a good ohmic contact.

From Fig. 5 the ideality factor n is calculated by using equation (8) and the slopes .However, this ideality factor gives value equal 2, this indicate that there is many different current a crossing the device like for example tunneling current etc.

It has been found that the SiC wafer can be easily oxidize by thin layer of oxide and this cause a series resistance on the surface in which it will effect the ideality factor .Figure 6 shows the I-V reverse bias and the current increases with increasing temperature and this is because the generation of the carrier in the depletion region, also it might be related to the existence of electron moving from the metal to the semiconductor. Now the interesting point as shown in Figure 6 the lines becomes linear after 1V, and this is because at high field the Schottky barrier is considerably low.

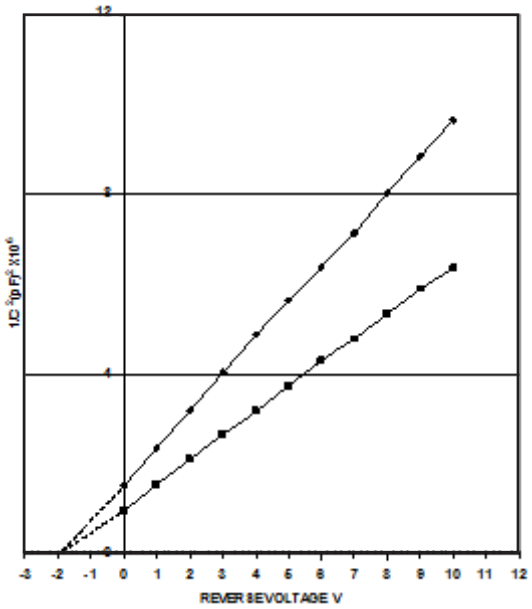

Fig. 2: The reciprocal of the square of the capacitance versus the reverse bias for Au p-4H SiC contact for two diodes on the same wafer. Diode diameter = 1 mm. The built-in voltage V_{bi} is found from the intercept with the voltage axis to be about 1.9 V.

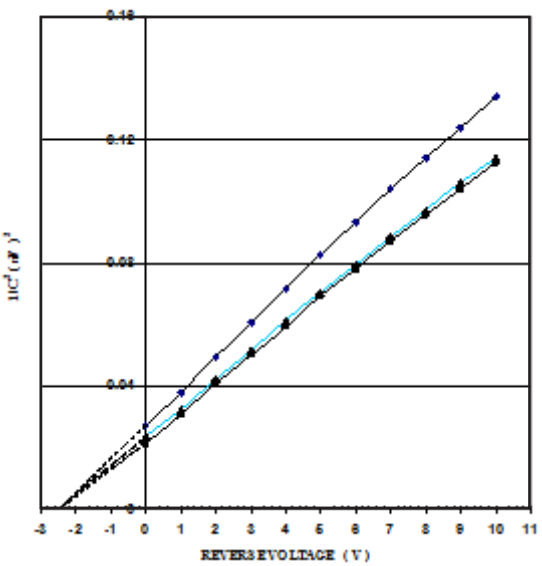

Fig. 3: The reciprocal of the square of the capacitance versus the reverse bias for Cr p-4H SiC contact for three diodes on the same wafer.Diode diameter = 1.7 mm. The built-in voltage V_{bi} is found from the intercept with the voltage axis to be about 2.4 V.

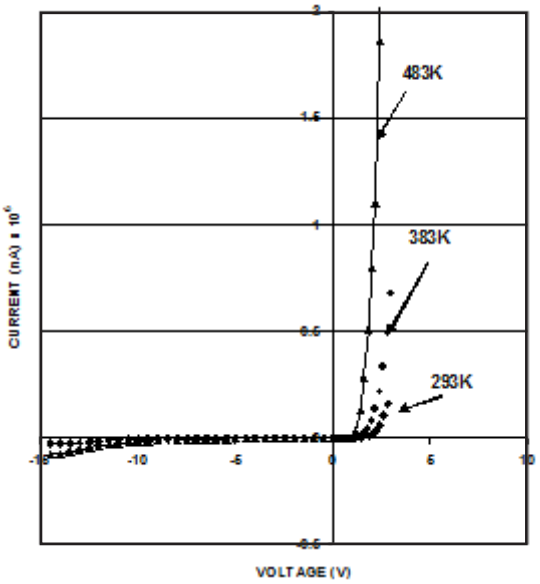

Fig. 4: Typical current-voltage characteristics with the temperature as a parameter of the Cr-p 4H SiC contact.

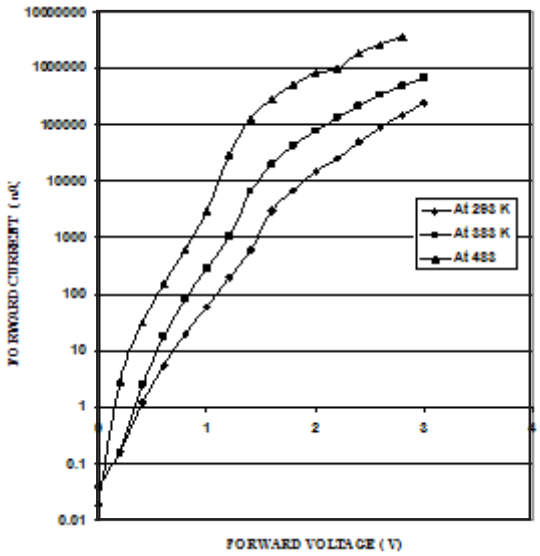

Fig. 5: Semi-logarithmic plot of the forward current-voltage characteristics of the Cr-p 4H SiC contact with the temperature as a parameter.

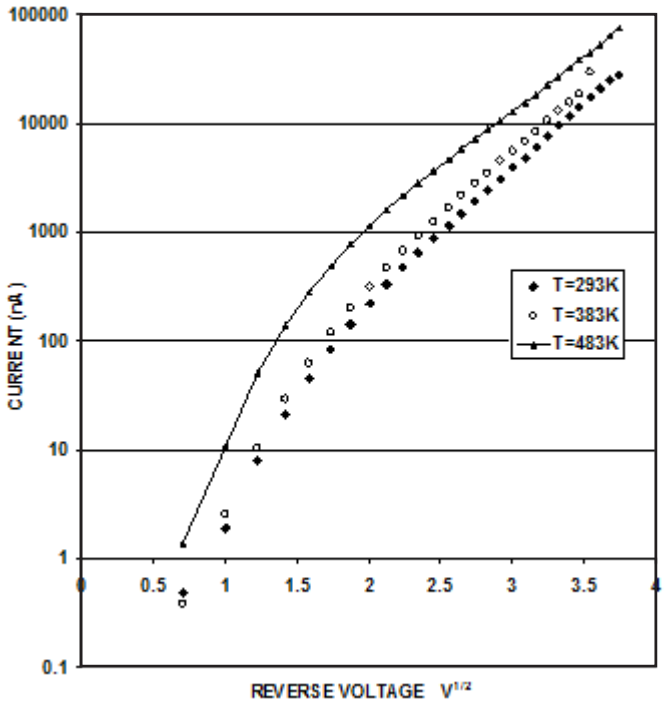

Fig. 6: Current versus the square root of the reverse voltage for the Cr-p 4H SiC contact.

Conclusion

The metal semiconductor contacts have been studied in this work. The 4H-SiC has been used as substrate and the Au as well as Cr has been used as contacts. Thermal evaporation with pressure of 10^{-5} Toor was maintained during the evaporation process, molybdenum boat was heated up by dc-current ranging from 60 to 80 Ampere. The electrical characteristics of the I-V and C-V for the device were measured as function of temperature, useful information related to the nature of the devices have been obtained, I-C-Voltage measurements give us suitable data for the doping concentration, deep levels , as well as the barrier height.

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