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The Temperature Effect on I - V_t Characterization of Heavily Doped SiC Metal Contact

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Abstract

Silicon Carbide is the most developed wide band gap semiconductor in crystal growth. In this study, a detailed experimental and theoretical analysis has been carried out for Au-SiC contacts. These metal-semiconductor contacts have been fabricated and electrically characterized experimentally as a function of temperature. Metal-semiconductor contacts were fabricated by thermal evaporation of gold (Au) on 4H-SiC wafers. Two Au-4H-SiC MS were fabricated one is p-type and lightly doped and another is n-type and heavily doped. Current-Voltage (*J*-*V*) was measured for both MS contacts as a function of temperature. Au-4H-SiC p-type was very good rectifier up to 400^{o}C. Its ideality factor was 1.73 at room temperature and decrease to 1.27 at 400^{o}C. The saturation current was 2×10^{-16} Amp/cm^2 at room temperature and increase to 1×10^{-6} Amp/cm^2 at 400^{o}C. n-type Au-4H-SiC contact was rectifier at low temperatures, but for more than 200^{o}C, it becomes non-rectifier contact.

Keywords: Temperature - effect on I-V_t SiC behaviour.

Introduction

A Wide Band Gap (WBG) semiconductor is defined as a semiconductor having energy band gap more than the conventional semiconductors . Silicon Carbide (SiC), Gallium Nitrite (GaN), and diamond(C) are examples for (WBG) semiconductors [6]. In this work, we concentrate our study on SiC, which is the most widely used WBG semiconductor. It is the more developed in crystal growth. Due to recent progress in SiC devices technology, high voltage Schottky diodes have been commercially available[3].SiC is polytypic semiconductor. There are more than 170 polytypes of

SiC [5]. 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 [1]. The building unit is a plane of Si atoms over a plane of C atoms. The difference between crystal structure and another is only in the stacking sequence of building units (double layer of Si and C atom). There are three possible positions of stacking a double layer on another [1].Reproducible process for producing the single crystal SiC was the hamper of development devices fabricated from it for many decades [4]. More researches were toward to development this processes. Today there are several methods to grow SiC single crystal such as physical vapor transport (modified Lely method), epitaxial growth, and hetero epitaxial growth.[2].

Experimental Work

Tow wafers of 4H-SiC were used to fabricate metal-semiconductor contact. One of them is lightly doped *p*-type with 421 μm thickness, the other is heavily doped n-type with 380 μm thickness. The shape of the wafers is quarter of cycle with 5 cm diameter. These wafers are from Cree Research Company, North Colorado, U.S.A. The metal used was gold having 99.95 purity. It was evaporated thermally in vacuum system to form a thin metallic film on SiC samples. About 20 diode were fabricated on each wafer. The diodes have circular cross section contact with small diameter between 1 to 3 mm.

Chemical cleaning

: Huge chemical method have been used (Alok, 1994). It was found that the most convenient to our laboratory facilities, and gives good results. SiC wafers were immersed in NH_4:H_2O_2:H_2O (1:1:5) for 10 minutes then washed in de-ionized water. After that, immersed in HCl:H_2O_2:H_2O (1:1:5) at 70^{o}C for 10 minutes. Finally, wafers washed in de-ionized water again, rinsed in Acetone, and dried by flow of nitrogen gas. It is important to note that, NH_4:H_2O_2:H_2O (1:1:5) and HCl:H_2O_2:H_2O (1:1:5) must be recently prepared. The old becomes less effective, because H_2O_2 decay with time to H_2O and O. It also should all chemical used must have high purity.

Vacuum System

Edward 306 vacuum coating unit was used for the evaporation of the metal on the SiC wafer. Coating units consist of rotary and oil diffusion pump to evacuate vacuum chamber (bell jar) to about 10^{-5} Torr. The system also equipped with two vacuum gauges, Penning and Pirani to measure the vacuum in the champers. There are two filament holder hold and heat the filament. There is substrate mask a bout 20 cm above the filament holders. Shutter (mechanical or electrical) can be used between vapour source and substrate . Quartz crystal usually placed inside the bell jar to measure and control the deposition rate and the film thickness.

Measurement Techniques

The current-voltage measurements were carried out by using *hp* 4140B unit. It consists of voltmeter and ammeter and power supply. This system was calibrated by using known resistance. The sample was kept inside a programmable oven. The circuit diagram is shown in Figure 1 .

(*J-V*) measurements and discussions

Current density- voltage (*J-V*) results are measured by using *hp* 4140B machine. Forward and reverse results in temperature rang from room temperature to 400°C are measured under vacuum. These measurements are shown in Figure 2 for p-type sample and Figure 3 for n-type sample. Figure 3 indicates that the contact of Au to p-type SiC works as very good rectifier until at high temperatures reache 400° C. For n-type sample, Figure 3 shows a small rectifying at low temperature (less than 200 °C). At high temperature (more than 200 °C), the contact behavior is smaller to that for ohmic contact. Analysis of forward and reverse bias will be discussed in the folloing sections.

Forward (J-V) measurements

Forward current density-Voltage (*J-V*) measurements at different temperatures are shown in Figure 4 for p-type sample and Figure 5 for n-type sample . It can be used to determine many Schottky diode parameters such as the Schottky barrier height(φ_b), the ideality factor (n), the effective area, and the series resistance (R_{SP}) of the diode. All these parameters have been calculated and found to be in good agreement with theoretical values [7] .

Reverse (J-V) measurements

The reverse current density –voltage characteristics of Au-4H-SiC Schottky rectifiers are shown in Figure 6 for p-type. We see that the reverse current is saturated. The ratio of J_F/J_R is about 0.7 million at 3 volt at room temperature. Also, the behavior of reverse current is independent of temperature. Only very small increasing in the reverse current is noted with increasing temperature.

For n-type Au-SiC contact, reverse characteristics are shown in Figure 7. For this contact, the reverse current is not saturated. It increases with the applied voltage, due to the following reasons [8] :

(1) field dependence of the barrier height. Schottky barrier lowering effect (image force lowering) and the presence of an interfacial layer are the commonest causes of field dependence of barrier height. All of these causes that φ_b should be a decreasing function of the maximum field strength in the barrier E_{max}. Since E_{max} increase with reverse bias V_R, it follows that φ_b decreases with increase V_R, and the current does not saturate but increase proportionally to $\exp(q\Delta\phi_B / kT)$, where $\Delta\varphi_B$ is the lowering of the barrier due to the electric field.

(2) 2-The effect of tunneling. This reason is important for Au-4H-SiC n-type since the sample is heavily doped.
(3) Generation in the depletion region.

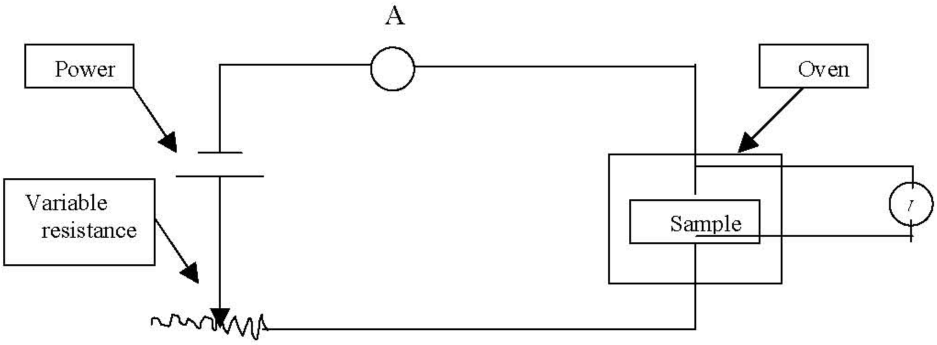

Figure 1: Equivalent circuit of I-V measurements.

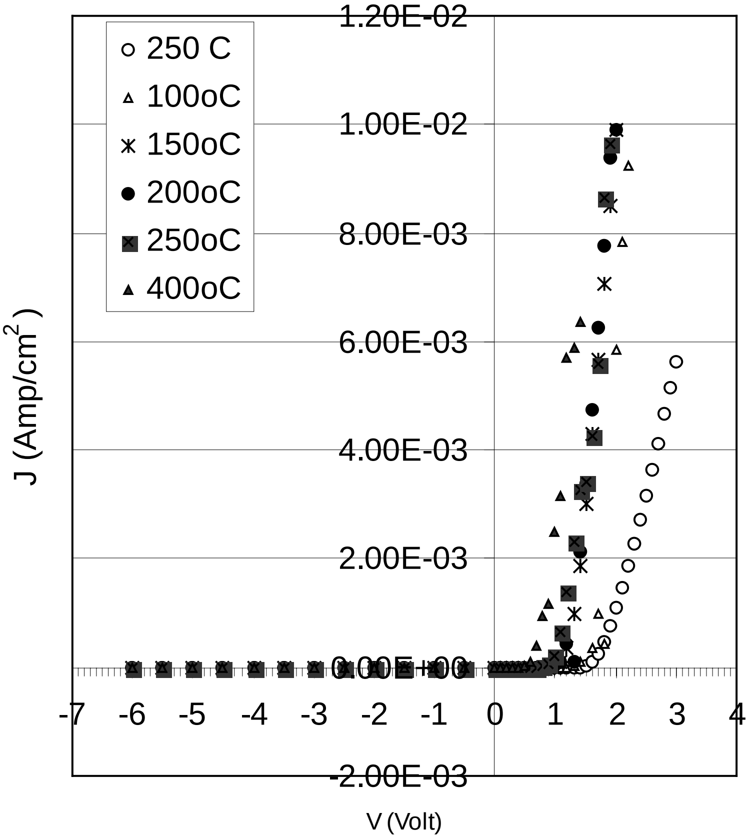

Figure 2: J-V_t results for Au-4H-SiC for p-type.

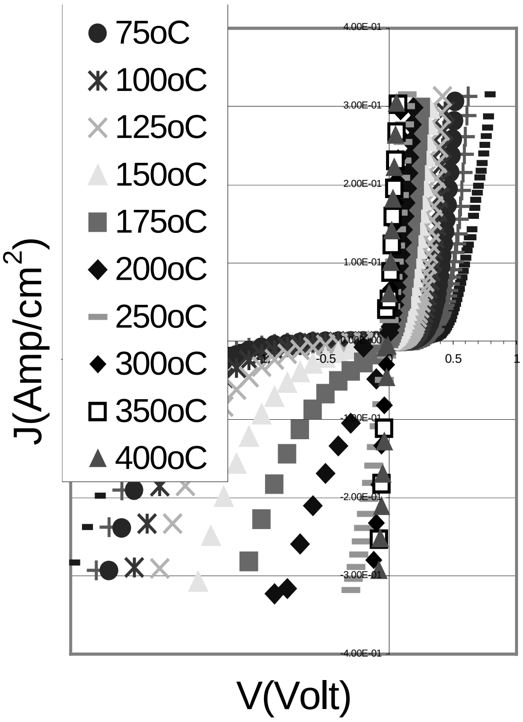

Figure 3: J-V_t results for Au-4H-SiC for n-type.

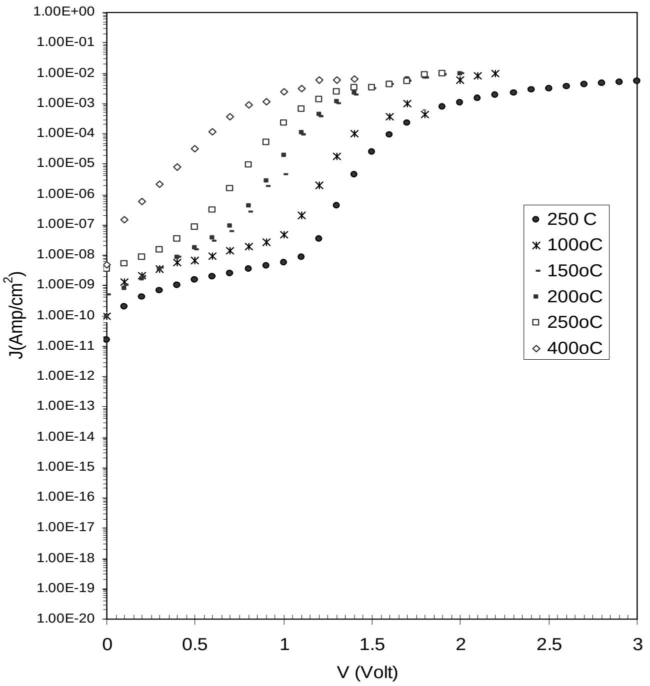

Figure 4: Forward J-V_t characteristics for Au-AH-SiC p-type sample.

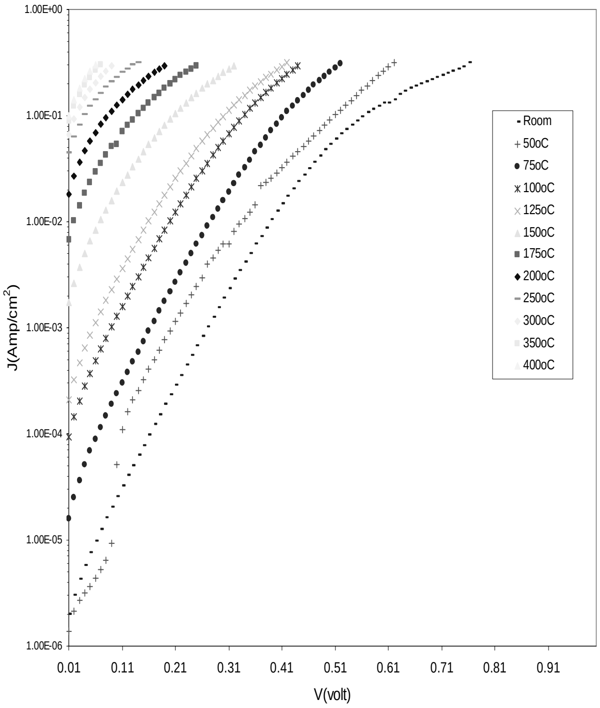

Figure 5: Forward J-V_t characteristics for Au-AH-SiC n-type sample.

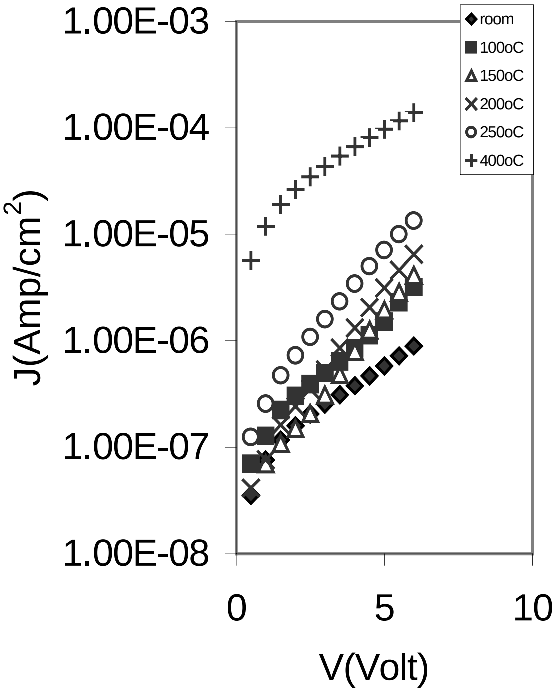

Figure 6: Reverse J-V_t characteristic of Au-4H-SiC p-type.

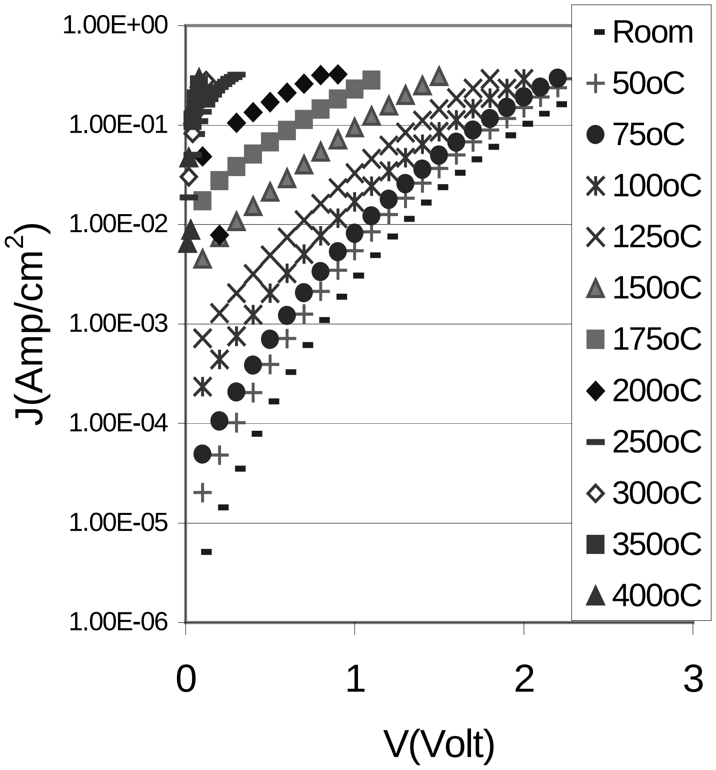

Figure 7: Reverse J-V_t characteristic of Au-4H-SiC n-type.

Conclusions

The above discussion indicates that the performance of metal-SiC contact is strongly affected by the doping concentration of SiC. The reverse current of Au-4H-SiC n-type, which is heavily doped, is orders of magnitude higher than that of Au-4H-SiC p-type sample, which is lightly doped. That is due to tunneling current, which increases with doping concentration .

Comparing barrier height calculated from *J-V* measurements for Au-4H-SiC with that reported for Ti-4H-SiC, there was no much difference in the barrier height. That means that the barrier height is approximately independent of kind of metal used. Such that independent happens in semiconductors with high-density surface of state .

Increasing of temperature leads to an improve in the forward characteristics of the diodes in hand and destroy the reverse characteristics in other hand. In forward bias, the voltage drop, ideality factor, and series resistance decrease with temperature. In reverse bias, the leakage current increase with temperature. That is due to thermoionic emission and tunneling mechanisms. The crystal defects may cause such that increasing in reverse current.

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