# Nickel and Palladium Contacts to 4H-SiC

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***Abstract*— SiC is prominent semiconductor for generation of power devices because of high breakdown field strength(~ 3MV $cm^{-1}$),high electron mobility(800 $cm^2$ $V^{-1}s^{-1}$) high electron saturation velocity ( $2x10^7$ $cms^{-1}$)and high thermal conductivity(4.9W $cm^{-1}$ $K^{-1}$).At the present time, one of the major limitations to the full performance of SiC-based devices is the Schottky and ohmic metal contacts. In particular, Schottky contacts with high Schottky barrier height (SBH) and good thermal stability are essential for operations involving high temperature, high gain, and low power consumption.In this study, the forward I-Vand C-V characteristics have been studied.Pd deposited on n-type 4H-SiC and schottky nickel contact made on the backside by electron-beam evaporation and annealed at temperatures of 200°C–400°C in vacuum were analyzed. The forward I–V characteristics were used to determine the effective barrier height and the ideality factor of Pd-SiCschottky contact. The aim of this study was to examine the effect of the annealing temperature on these parameters and study the I-V and C-V characteristics comparing the barrier height for the two.Also, all the qualities referred above favours 4H-SiC to be used as MOSFETs**

***Index Terms*— SiC, I-Vand C-V characteristics, 4H-SiC, SBH**

## I. INTRODUCTION

The interest in studying and integrating electronic components based on silicon carbide SiC semiconductor is increasing day by day in smart power circuitswhich is motivated by both the excellent physical properties of the silicon carbide and the increasing need of electrical engineering in the domains of high voltage. The silicon carbide has been listed as a considerable rival for the electronic systems that function in high temperature conditions[1]. It has a large bandgap of 3.3 eV at 300K and the highest electron mobility amongst alpha-SiC. Also the large bonding energy of the Si-C bond makes it resistant to chemicals.

4H-SiC is excellent for fabrication of high temperature schottky diodes because of its excellent material properties. It has been used in the fabrication of many electronic devices in PN diodes, MOSFET, IGBTs, pressure and temperature sensors. However, there are certain problems associated with 4H-SiC. For the purpose of industrial applications the quality of 4H-SiC is lower as compared to Si.

However, the studies reveal that Schottky contacts to 4H-SiC exhibit non-idealities and Schottky barrier inhomogeneities. Thermal annealing has been reported to be a necessary step to improve the diode characteristics. It has been found that thermal annealing favoured the Ni/4H-SiC contact formation and reduced the thickness of the insulating interlayer, thereby improving the idealityfactor[2]

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The structure of Pdschottky contact to 4H-SiC with ohmicNickel contact at the backside and its I-V and C-V characteristics were plotted in Silvaco TCAD. The fundamental parameters, namely, barrier height and ideality factor are extracted from these curves.The effect of annealing on the structure is observed as well.

## II. EXPERIMENTAL DETAILS

The current work involves Palladium Schottky contact to 4H-SiC with backside Nickel Ohmic contact. Initially the sample was cleaned with Trichloro ethylene acetone Methanol and DI water. The cleaned sample was rinsed in an ultrasonic agitator in 5 minutes. Again the sample was cleaned in mixture of HCl, $H_2O_2$ and DI water taken in a proportion of 1:1:5 for 5 minutes. After that the sample is dipped in HF solution followed by DI water.

The Ohmic contact wasformed on the backside with Nickel deposited with a thickness of 300Å using electro beam evaporation technique. Vaccuum level was maintained at $10^{-6}$ during the process. An annealing step was carried out at $600^0$C in a Nitrogen ambient for 5 minutes.

After this the Schottky contact of Palladium in the form of rectangular dots of 1mm length and thickness 300Å was deposited using electro beam evaporation technique.

Finally the I-V and C-V measurement were carried out for the diode sample using Keitheley Source Measurement Unit 2400 and Deep Level Transcient Spectrometer CDLS-83D respectively.

### *A. Structure in Silvaco TCAD*

A Schottky diode of 4H-SiC of n-type with doping concentration of 5 x $10^{18}$ /$cm^3$ and thickness of 347µm having metal contact of Palladium of 1mm length and thickness 300 Å is formed at the top and Ohmic contact of Ni of thickness 300 Å is formed at the bottom. Then annealing is done at $600^0$C for 5 minutes in nitrogen ambient.

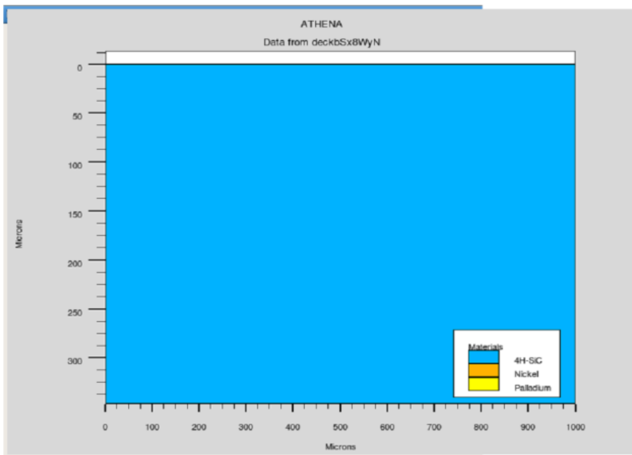


Fig1: Device structure simulated in athena from silvaco TCAD

## III. Metal Semiconductor Contacts

Most of the semiconductor devices that make up an integrated circuit are connected by means of metal-semiconductor contacts. Moreover, all integrated circuits communicate with the rest of the electrical system via metal-semiconductor contacts.

When a wide band gap semiconductor is considered, such as SiC or even GaAs, we have some difficulties in the metal choice. This is mainly due to the fact that the typical values for the work function of the commonly employed metals are less than 5 eV, and the electronic affinities are close to 4eV. In order to overcome this problem, a high doping of the wide band gap semiconductor is usually performed before the ohmic contact fabrication. Metal – silicon carbide contacts with rectifying characteristic are of great importance in view of Schottky diodes or field – effect transistors fabrication, in order to fully exploit the excellent properties of silicon carbide, especially when the polytype 4H is considered. Furthermore, an ohmic contact to silicon carbide with a low on – resistance and good reliability is needed for the fabrication and the commercialisation of SiC – based devices. Some of the prominent metal contacts to SiC are Nickel Platinum Titanium Palladium Chromium etc.

For the Ni/SiC contact structure to become ohmic it is annealed in vacuum at temperatures higher than 900°C usually for 10 minutes and a solid state reaction takes place between Ni and SiC. Ni silicides and carbon phases are formed during the reaction. Contact resistivities of these contact structures are fairly low, but the reaction including SiC decomposition is undesirable. Additional thermal treatment improves the contact.Also influence of post metallization annealing in Ar gas ambient on schottky contact metal when done, causes effect on both Ni crystallinity and the adherence on semiconductor. On the other hand it improves its electrical properties.

### A. *Palladium contacts to SiC*

Palladium contacts of 1mm length and thickness 300 Å were made at the top of the 4H-SiC substrate. These form schottky contacts with the substrate material.

### B. *Nickel contacts to SiC*

Nickel can form both schottky and ohmic contacts. For the contact to be ohmic, it is annealed at higher temperature. While ohmic contact was annealed at $600^0$C, formation of nickel silicides($Ni_2Si$) takes place which causes number of carbon vacancies to occur.

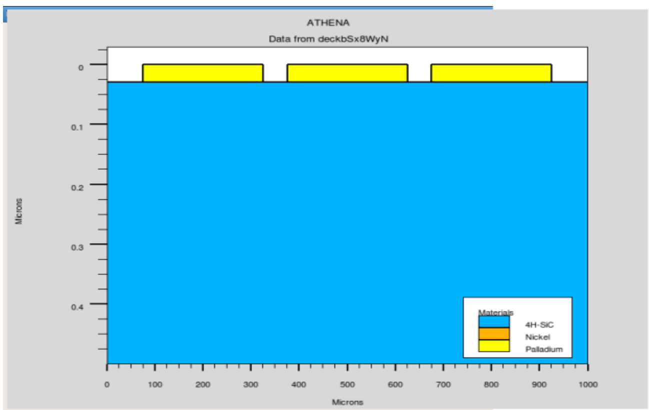


Fig2:Pdschottky contacts made on top of 4H-SiC

## IV. Simulation using Silvaco TCAD

**ATHENA** is a group of process simulation products that enables process and integration engineers to develop and optimize semiconductor manufacturing processes. ATHENA provides a platform for simulating ion implantation, diffusion, etching, deposition, lithography, oxidation, and silicidation of semiconductor materials. It replaces costly wafer experiments with simulations.

**ATLAS** is a group of device simulation products enables device technology engineers to simulate the electrical, optical, and thermal behaviour of semiconductor devices. It provides a physics-based, modular, and extensible platform to analyze DC, AC, and time domain responses for all semiconductor based technologies in 2 and 3 dimensions.

In short Athena is used to give the fabrication process details into the DeckBuild editor and Atlas is used to plot the electrical characteristics of the fabricated device using another feature called TonyPlot. For eg: the fabrication details of, say, a diode is described in Athena. Once this is done, Atlas is invoked to analyze the I-V and C-V characteristics of the device. The results are then plotted using Tony Plot.

## V. Results and Discussions

The I-V plot for 4H-SiC is shown below for different temperatures as deposited $200^0$C, $300^0$C, $400^0$C.As annealing temperature was increased it was observed that the contact behaviour turns towards ohmic. The ideality factor close to one indicates ideal schottky behaviour. As this value increases above 1 it shows that the interface traps and effects are coming in account. Also, as the annealing temperature increases, ideality factor shifts towards that of an ideal diode. The barrier height also shows improvement. Figure 3 shows the I-V characteristics at different annealing temperatures. The ideality factor was computed using [1]

$$I=AA^*T^2\exp\left(-\frac{q\varphi_B}{kT}\right)\left[\exp\left(\frac{qV}{kT}\right)-1\right][1]$$

Where Is= A $A^*T2\exp\left(-\frac{q\varphi_B}{kT}\right)$ is reverse saturation current and Richardson constant $A^*=146\ cm^2/K^2$

While ohmic contact was annealed at $600^0$C, formation of nickel silicides occur which causes number of carbon vacancies to occur. These vacancies plays a dominant role in formation of ohmic contact.

| temperature | Ideality factor | Barrier height |
|---|---|---|
| As-deposited | 2.56 | 0.802 |
| $200^0$C | 3.8 | 0.92 |
| $300^0$C | 1.71 | 0.607 |
| $400^0$C | 1.63 | 0.9 |

Table1: Measured values of barrier height and ideality factor

## VI. Conclusions

Figure 4 shows the I-V characteristics simulated using Silvaco TCAD tool. The characteristics shows that the diode works properly under normal conditions. Figure 5 shows I-V characteristics with varying temperatures. It depicts that as temperature increases, the reverse saturation current also increases. Also the C-V characteristics reveal that as temperature decreases, the characteristics shift towards reverse bias voltages.

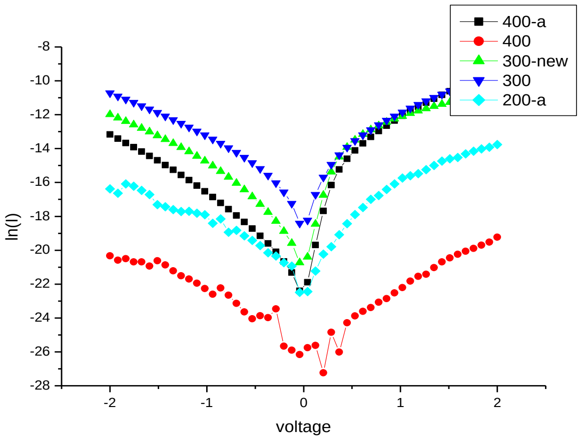


Fig 3: I-V characteristics for different annealing temperatures

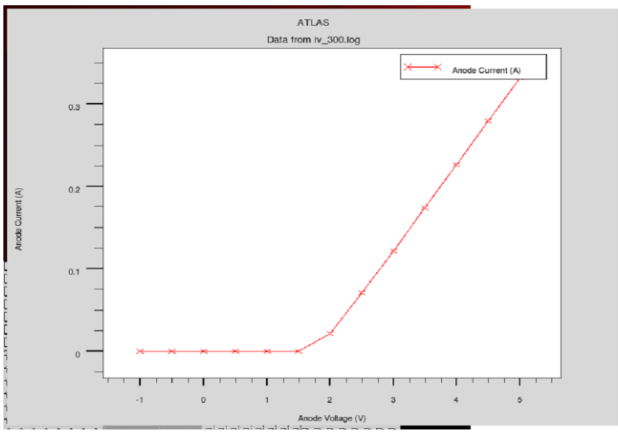


Fig 4: The I-V characteristics

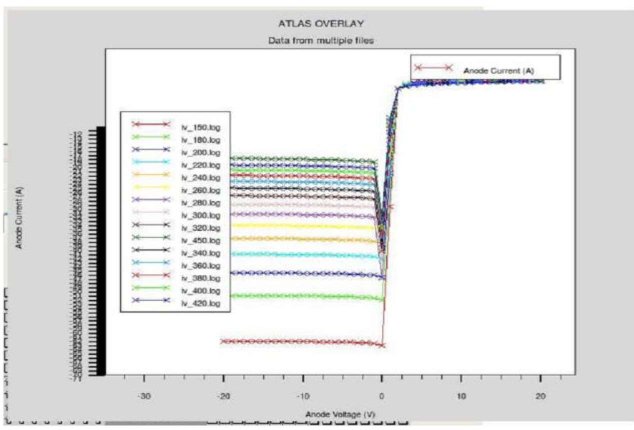


Fig 5: I-V-T characterisiticsThe overall characteristics of the device when anode voltage varied from -30 V to 20 V

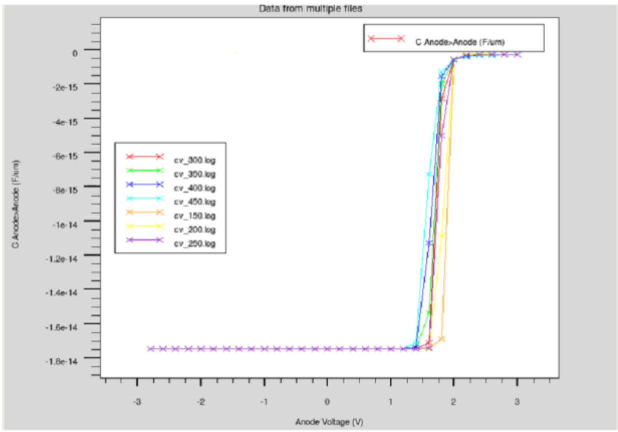


Figure 6: C-V-T Characteristics at 1MHz frequency

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