THE EFFECT OF THE POST-METALLIZATION ANNEALING OF Ni/n-TYPE 4H-SiC SCHOTTKY CONTACT

R. Pascu[1], F. Craciunoiu[1], M. Kusko[1], F. Draghici[2,1], A. Dinescu[1], M. Danila[1]

[1]National Institute for Research and Development in Microtechnologies, IMT Bucharest, Romania
E-mail: razvan.pascu@imt.ro, florea.craciunoiu@imt.ro, mihaela.kusko@imt.ro, adrian.dinescu@imt.ro, mihai.danila@imt.ro
[2]POLITEHNICA University Bucharest, Romania
E-mail: florin.draghici@dce.pub.ro

Abstract–*The Schottky diode for temperature sensor based on 4H-SiC is presented. This paper is focused on the improvement of the Schottky contact and interface stabilization using an annealing in Ar atmosphere. The diodes have been measured in range of temperature 50-150°C.*
Keywords: *silicon carbide (SiC), Schottky contact, Schottky Barriere Diode (SBD).*

1. INTRODUCTION

Silicon carbide (SiC) is a material with excellent electrical properties, important for development of power devices [1-2], but difficult and expenses to process. Due to its high temperature stability, fabrication of SiC based Schottky diode as temperature sensor is one of the primary applications [3-6]. In this view, our work is focused on development of a reliable technology for improving the Schottky contacts on n-type 4H-SiC substrate.

In the last decade, several studies concerning Schottky contacts on SiC have been performed to select the most advantageous contact metal. Cr and Ti have been tested also for Schottky contact [7-8], but we have shown in a previous paper [9], that Ni is more appropriate, due to the low electrical resistivity at room temperature and thermodynamic stability.

Recent studies have reported the necessity of an additional thermal treatment for improving of Ni / SiC Schottky contact, usually in an inerte atmosphere [10-11]. Accordingly, the vacuum or inert gas ambient annealing could be a suitable method to improve the properties of metal-semiconductor interface.

In this paper the influence of post-metallization annealing in Ar gas ambient on the Schottky contact metal has been investigated, showing on one hand the effects on both the Ni cristallinity and the adherence on semiconductor surface, and on the other hand the improving of electrical characteristics.

2. TECHNOLOGY

A $n^{++}/n^{+}/n^{-}$ type 4H-SiC wafer of 1μm (n^{+} doped concentration of $10^{-18}cm^{-3}$), respectively 36.5 (n^{-} doped concentration of $2.23 \cdot 10^{-15}cm^{-3}$) epitaxial layers on Si face, 7.93° off axis oriented, 0.020 Ω·cm resistivity purchased from Cree Inc., was used.

In order to obtain an effective edge termination that makes the electric field distribution uniform at the bulk and at the electrode corner of the device, the diode design contains a small oxide ramp of surrounding anode contact window where the metal overlaps upon the oxide layer. The section of the diode structure is schematic presented in figure 1:

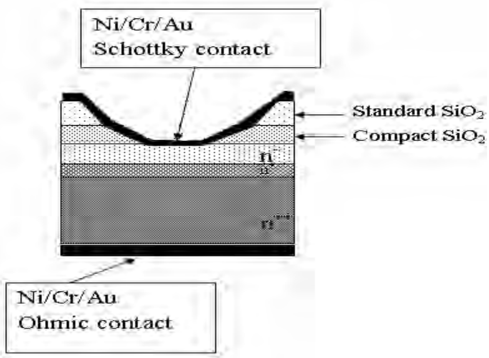

Fig. 1. Schematic cross section of metal/4H- SiC Schottky diodes.

Conform to theoretical analysis, when the oxide ramp became less than 10° electric field peak at metal transition from Schottky contact to oxide is attenuated, and our previous efforts have been dedicated to obtain experimentally this type of structure [9]. In Fig. 2 is presented the cross-section mirror SEM image of the diode structure before metal deposition.

978-1-4673-0738-3/12/$31.00 © 2012 IEEE

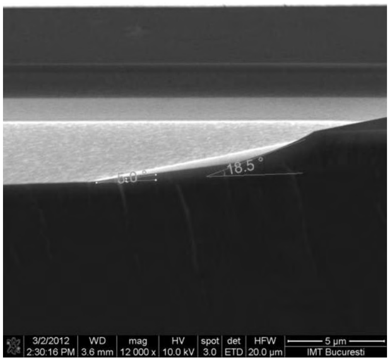

Fig. 2. SEM micrography of the experimental structure with two angle ramps.

As it can be see, the first ramp has a 5° angle, leading to a proper operation of the device by an uniform current flow and an ideal breakdown voltage [9]. Furthermore, these angles of ramps oxide termination provide a formation of a good Schottky contact.

The next step for achievement of the Schottky diode on SiC is the metal deposition leading to Ni/4H-SiC Schottky contact. Taking into account the structure profile, a sputtering process have been utilised for a good uniformity of the film. However, this process is not a trivial one, the parameters for a correct deposition being obtained after successive tests. For instance, we have observed at 130 minutes deposition time the presence of an exfoliation (Fig. 3.a); instead, at 90 minutes deposition time and a good adherence of the deposited film (Fig. 3.b):

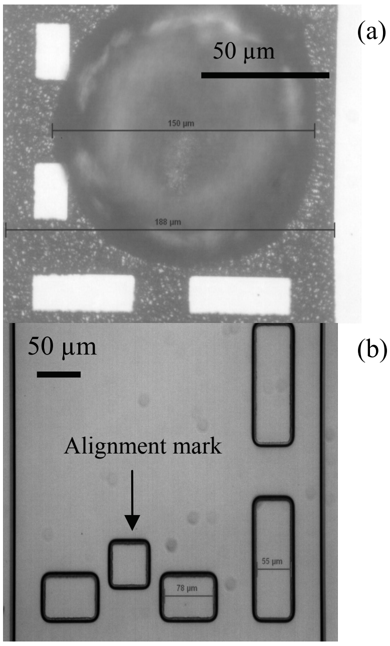

Fig. 3. Optical images of Ni deposition using different process parameters.

Regarding the metallic layer thickness, while at 130 minutes deposition time is 350 nm, after 90 minutes is 250 nm.

After the first photolithographic process, which consisted in opening of windows in oxide for Schottky contact, a second photolithographic process for defining active areas was necessary. The mask layout has been designed with four very different diode areas for investigating the performance of the sensor device area, where the diode D1 is connected to a single area of 4000 µm^2. For diode D2 are connected two such areas. Diode D3 has an area of 16000 µm^2 and D4 is connected to all four active areas, having an area of 24000 µm^2.

The improvement of the Schottky contact is conditioned by post-metallization annealing. A rapid thermal process has been proposed for this scope, using the RTP AS One system. Therefore, the temperature is raised with a step of 25°C/s up to 500°C, after that, being kept constant for 2 minutes. Finally, the temperature is slowly decreased, with a 5°C/s step down to 300°C, and then the chamber is abruptly cooled.

To see the effect of the post-metallization annealing process, a X-Ray analysis has been performed, before and after annealing. The measurements have been done with 9kW rotating anode SmartLab Rigaku diffraction system in grazing incidence (ω=0.5°) set-up. The diffraction patterns obtained for metallic (Ni) layer, before and after annealing are presented in Fig. 4:

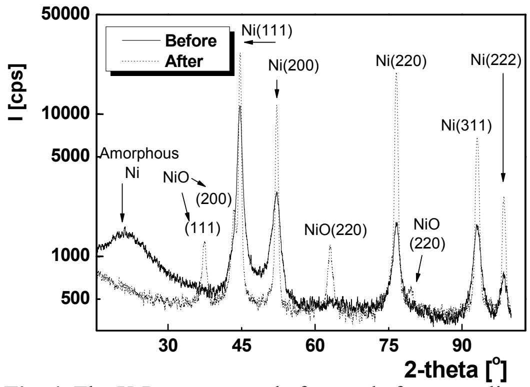

Fig. 4. The X-Ray patterns, before and after annealing, for the Ni deposited layer on SiC.

We can see that before RTA a significant amorphous Ni phase is present in the XRD spectra (large hump at 2θ = 21.5°). After the RTA step one can see a complete crystallization of the deposited film and also a slight oxidation of it. The Ni mean crystallite size is growing from 52Å before RTA to 217Å after RTA (FWHM of every Ni peak is decreasing after RTA, and diffracted intensities are highly raised). After RTA the film is fully crystalline.

3. ELECTRICAL CHARACTERIZATION

The Schottky diodes (SD) have been measured at room temperature varying voltage from 0 to 2V with a step of 20mV. The measurements at room temperature (RT) have been done with I-V characterization system, SCS 4200 Keithley. Fig. 5 shows forward I-V characteristics of Ni/4H-SiC SD's measured at RT before and after metal treatment:

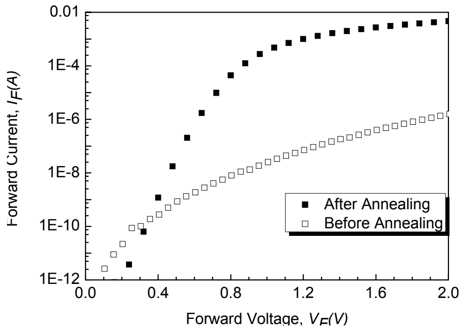

Fig. 5. I-V characteristics, at room temperature, before and after annealing.

It can be see an increasing of current and an exponentially characteristics that covers many orders of magnitude, after annealing.

Since the Schottky diodes based on SiC are used in a thermal sensor, the measuremens at different temperatures presents a higher interest. In this scope, the measurements have been done on wafer, choosing one structure with four different areas. These have been measured using a HP 4145 semiconductor analyser and a wafer heating system. The measurements have been done at five different temperatures between 50 and 150°C, the results being presented in Fig. 6:

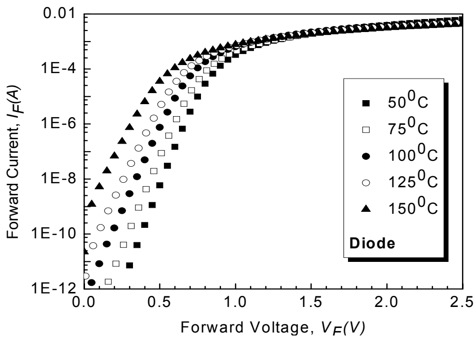

Fig. 6. The behavior of Schottky diode based on SiC at different temperatures.

It is found that the current increases with temperature. From a linear fit on the exponentially characteristic of the logarithmic forward I–V plots, ideality factor (n) and barrier height (Φ_{Bn}) have been calculated by the slopes and intercepts of the linear fits. The determined values of n and Φ_{Bn} are presented in Fig. 7 as a function of the temperature.

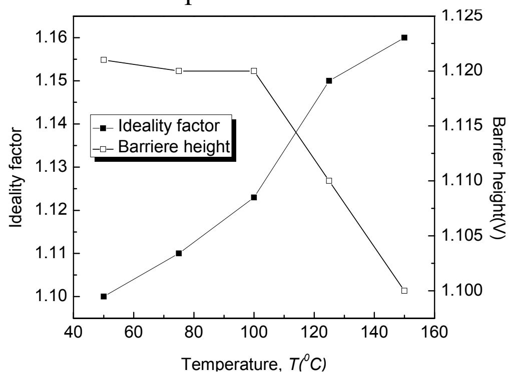

Fig. 7. Temperature dependence of the experimental barrier height Φ_{Bn} and experimental ideality factor (n).

We can see that while the Φ_{Bn} decreases with increasing of temperature, the n increases, so that the product (n Φ_{Bn}) is constant with temperature according to thermionic emission law. [12]

$$V_F(T) = n\phi_{Bn} - [n\phi_{Bn} - V_F(T_0)]T / T_0 \qquad (1)$$

where T_0 is the reference temperature.

The values for these parameters, as we can see in Fig. 7, are: Φ_{Bn}=1.121V and n=1.1 at T=50^{0}C and Φ_{Bn}=1.1V and n=1.16 at T=150°C.

An important feature for a thermal sensor, based on Schottky diode, is sensibility. It represents the necessary voltage to produce a temperature change of 1K and is defined by the equation: [12]

$$S(T) = [n\phi_{Bn} - V_F(T_0)] / T_0 \qquad (2)$$

The graphs of forward voltage as a function of temperature measured at several constant currents are presented in Fig. 8:

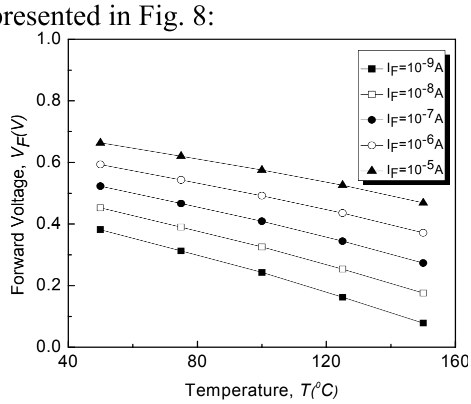

Fig. 8. Forward voltage as a function of temperature measured at several constant currents.

The graphs demonstrate that V_F linearly decreases in the range of temperature and increases with the growth of bias current. Furthermore, the sensor sensibility (S) has been determined by linear fit of the straight lines in Fig. 8 and the slopes representing the value of sensibility, illustrated in Fig. 9:

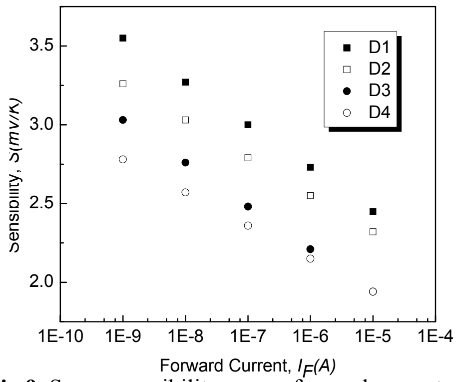

Fig.9. Sensor sensibility versus forward current.

The graphs' analyses show that the sensibility decreases with the growth of the bias current and active area.

4. CONCLUSIONS

Schottky diodes based on SiC for temperature sensor have been designed and characterized. It has been observed that a rapid thermal annealing post-metallization process leads to improving of the Ni crystallinity, and consequently of the Schottky diode characteristics. The test diodes have been measured on wafer in range of temperature 50-150^{0}C and a good linearity in the whole temperature range has been achieved. Furthermore, the sensibility of the SD's sensor has been analysed, being [1.94-3.55] mV/K for a forward current variation with 5 orders of magnitude.

Acknowledgement–The research presented in this paper is supported by the Sectoral Operational Program Human Resources Development (SOP HRD) financed from the European Social Fund and by Romanian Government under the contract number POSDRU/89/1.5/S/63700.

References

[1] S. Nigam, Jihyun Kim, B. Luo, F. Ren, G.Y. Chung, J.R. Williams and S.J. Pearton, "Simulation and experimental characteristics of 4H-SiC Schottky power rectifiers", *Electrochemical society proceedings*, **14**, 2002.

[2] T.N. Oder, P. Martin, A.V. Adedeji, T.Isaacs-Smith and J.R. Williams, "Improved Schottky Contacts on n-Type 4H-SiC Using ZrB2 Deposited at High Temperatures", *Journal of electronic materials*, 2007.

[3] S. Sankar Naik, V. Rajagopal, Reddy, "Electrical Transport Characteristics and Deep Level Transient Spectroscopy of Ni/V/n-InP Schottky Barrier Diodes", *Journal of nano- and electronic physics,* **4(**2), 2012.

[4] Cyril Buttay, Christophe Raynaud, Herv´e Morel, Gabriel Civrac, Marie-Laure Locatelli, Florent Morel, "Thermal stability of silicon-carbide power diodes", *IEEE Transactions on electron devices*, pp, 99, 2012.

[5] T. Funaki, J.C. Balda, J. Junghans, A.S. Kashyap, H. A. Mantooth, F. Barlow, T. Kimoto, and H. Takashi, "Power Conversion With SiC Devices at Extremely High Ambient Temperatures," *IEEE Transactions on power electronics*, **22**(4), pp. 1321–1329, jul. 2007.

[6] C. Buttay, D. Planson, B. Allard, D. Bergogne, P. Bevilacqua, C. Joubert, M. Lazar, C. Martin, H. Morel, D. Tournier, and C. Raynaud, "State of the art of High Temperature Power Electronics," *Proceedings of the VIII conference thermal problems in electronics*, Lodz, Poland, jun. 2009.

[7] Song Qing-Wen, Zhang Yu-Ming, Zhang Yi-Men, Chen Feng-Ping and Tang Xiao-Yan, "Investigation of current transport parameters of Ti/4H SiC MPS diode with inhomogeneous barrier", *Chin. Phys. B* **20**(5), 2011.

[8] Shaweta Khannaa, S.Neeleshwara, Arti Noorb, "Current –voltage-temperature (i-v-t) characteristics of Cr/4H-SiC Schottky diodes", *Journal of Electron Devices*, **9**, pp. 382–389, 2011.

[9] R. Pascu, F. Draghici, M. Badila, F. Craciunoiu, G. Brezeanu, A. Dinescu, I. Rusu, "High temperature sensor based on SiC Schottky diodes with undoped oxide ramp termination", *Proc. of the 34th International Semiconductor Conference*, **2**, pp. 379–382, 2011, Sinaia, Romania

[10] A. Sefaoglu, S. Duman , S. Dogan, B. Gurbulak, S. Tuzemen, A. Turu t, "The effects of the temperature and annealing on current–voltage characteristics of Ni/n-type 6H–SiC Schottky diode", *Microelectronic Engineering* **85,** pp. 631–635, 2008.

[11] Sanjeev K. Gupta, A. Azam , J. Akhtar, "Improved electrical parameters of vacuum annealed Ni/4H-SiC (0 0 0 1) Schottky barrier diode", *Physica B*, pp. 3030–3035, 2011.

[12] F. Draghici, M. Badila, G. Brezeanu, I. Rusu, F. Craciunoiu, I. Enache, "An industrial temperature probe based on SiC diodes", *Proc. of the 33rd International Semiconductor Conference*, **2**, pp. 409–412, Sinaia, Romania, 2010.