



HAL
open science

Investigations on Ni-Ti-Al ohmic contacts obtained on p-type 4H-SiC

Farah Laariedh, Mihai Lazar, Pierre Cremilleu, Jean-Louis Leclercq,
Dominique Planson

► **To cite this version:**

Farah Laariedh, Mihai Lazar, Pierre Cremilleu, Jean-Louis Leclercq, Dominique Planson. Investigations on Ni-Ti-Al ohmic contacts obtained on p-type 4H-SiC. HeteroSiC & WASMPE 2011, Jun 2011, Tours, France. pp.169-173, 10.4028/www.scientific.net/MSF.711.169 . hal-00661507

HAL Id: hal-00661507

<https://hal.science/hal-00661507>

Submitted on 9 May 2019

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Investigations on Ni-Ti-Al ohmic contacts obtained on p-type 4H-SiC

F. Laariedh^{1, a}, M. Lazar^{1, b}, P. Cremillieu^{2, c}, J.-L. Leclercq^{2, d} and D. Planson^{1, e}

^{1,2} Université de Lyon, CNRS,

¹INSA-Lyon, Laboratoire AMPERE, UMR 5005, F-69621 Villeurbanne, France

²ECL-Lyon, Institut des Nanotechnologies de Lyon (INL), UMR 5270, F- 69134 Ecully, France

^afarah.laariedh@insa-lyon.fr, ^bmihai.lazar@insa-lyon.fr, ^cpierre.cremillieu@ec-lyon.fr, ^djean-louis.leclercq@ec-lyon.fr, ^edominique.planson@insa-lyon.fr,

Keywords: Silicon Carbide, Ohmic contact resistance, Nickel, TLM, SIMS, EDX,

Abstract. Transfer Length Method (TLM) based-structures were fabricated on 0.8 μm -thick epitaxial p-type Silicon Carbide (4H-SiC) layers. TLM mesas were defined by a 2 μm height using an SF_6/O_2 reactive ion etching. TLM metal patterns were obtained by a lift-off procedure and electron beam deposition of Ni, Ti, Al and Pt. The patterned samples were annealed in Argon ambient at temperature ranging from 700°C up to 1000°C in a RTA furnace with a rapid heating ramp (up to 50°C/s) to complete the ohmic contact with the p-type SiC layer. Specific contact resistances were extracted from current/voltage measurements. To identify and follow the profile evolution of constituting element in the contacts and at the SiC/contact interface, the ohmic contacts were characterized using Secondary Ion Mass Spectrometry and Energy-Dispersive X-Ray spectroscopy before and after annealing. Ohmic contacts are obtained only for the Ni/Ti/Al and Ni/Ti/Al/Ni stacking layers and not for the Ti/Al/Ti/Ni and Ti/Al/Ti/Pt/Ni compositions. The specific contact resistance of Ni/Ti/Al/Ni stacking layers was observed to decrease from $2.7 \times 10^{-4} \Omega \cdot \text{cm}^2$ at 700°C and $6.3 \times 10^{-5} \Omega \cdot \text{cm}^2$ at 750°C to a minimal value of $1.5 \times 10^{-5} \Omega \cdot \text{cm}^2$ at 800°C. Ohmic contacts are obtained with a reproducibility of 80 %.

Introduction

Silicon carbide (SiC) is a promising wide bandgap semiconductor material for high temperature, high-power and high-frequency device applications. However, there are still a number of factors that are limiting the device performance. Most SiC-based electronic devices which cannot sustain a long-term operation at high power and/or temperature suffered deterioration of their metal/SiC contacts. Therefore, one of the most important and critical factor is the formation of low resistivity ohmic contacts with good thermal, mechanical and chemical stability on silicon carbide [1,2].

From the literature, we can find many difficulties in the realization of the ohmic contacts to p-type SiC, due to its wide bandgap value and its incompatibility with the work functions of the usual metals used for ohmic contact fabrication. To answer to this problem, it is generally necessary to choose metals with low Schottky barrier, lowering this barrier height by annealing to form a silicide at the metal-SiC interface, and by overdoping p-type SiC layer close to the metal contact.

Several metals have been investigated for the preparation of ohmic electrical contacts. Among them, nickel, titanium, aluminium and platinum have attracted more attention as ohmic contact for p-type SiC, due to their relatively low contact resistivity obtained. Many groups have obtained ohmic contact using Ni or Ni/Ti with specific contact resistance in the order of $10^{-3} \Omega \text{cm}^2$ [2], since these metals are successfully used in the fabrication of ohmic contacts to n-type SiC layers [3-4].

Nevertheless, the achieved specific resistances on p-type SiC layers are not enough low for reliable power or high temperature applications. To improve the quality of these contacts, aluminium based metals such as Ti/Ni/Al, Ni/Al and Al/Ti have been studied resulting in specific contact resistances lower than $1 \times 10^{-4} \Omega \text{cm}^2$ [5-7]. Ni presence in these alloys seems to decrease the

annealing temperature required to obtain ohmic contacts as Ni reacts with SiC from 500°C [5]. For the Al-Ti alloy, the ohmic behaviour remains very sensitive to the Al content. For the configuration of Al(90%) Ti(10%) in weight the lowest specific resistance is $1 \times 10^{-6} \Omega \cdot \text{cm}^2$ but not reproducible [8]. On the other hand, the Al(70 %) Ti(30 %) composition represents the best compromise for a good contact with a reproducibility of specific resistance of the order of $1.10^{-5} \Omega \text{cm}^2$ [9-10].

Al, which is also a p-type dopant for SiC, is generally considered as an element responsible for forming ohmic contacts on p-type SiC, producing a heavily p-type doped region near the SiC/metal interface [8]. Thus, to fabricate low resistance contacts, high concentration of Al is believed to be necessary. However, its chemical and thermodynamical instability requires that a secondary metal is necessary to form stable ohmic contacts when Al based films are used [10]. Alternative materials such as co-evaporation of TiC and sputtered TiW have been studied to form ohmic contacts on high doped p-type SiC obtaining specific ohmic resistance of several $10^{-5} \Omega \text{cm}^2$ [11].

In this paper, we report on the investigation of evaporated Al-Ti-Ni metal-based ohmic contacts to p⁺-type 4H-SiC. We selected Ni as the key contact element, because its ability to form Ni₂Si alloy at low temperatures as 500°C [4,5,12]. Ti was added to the Ni/Al contacts to prevent the formation of unreacted interfacial carbon atoms [13]. It has been also argued that the formation of the alloy Ti₃SiC₂ is favoring the formation of the ohmic contact [7] but its role remains to be proved [14].

Metal contact composition	Thickness of the layers (nm)
Ti-Al-Ti-Pt-Ni	4-60-100-25-25
Ti-Al-Ti-Ni	5-60-30-100
Ni-Ti-Al	25-50-300
Ni-Ti-Al	12.5-25-150
Ni -Ti-Al- Ni	12.5-50-300-12.5
Ni -Ti-Al- Ni	10-40-240-10
Ni -Ti-Al- Ni	5-20-120-5

Table 1: Thicknesses of Ni, Al, Pt and Ti layers deposited on SiC p-type epilayers.

Experimental

Transfer Length Method (TLM) based-structures were fabricated on 0.8 μm-thick epitaxial p-type ($N_A = 3 \times 10^{19} \text{ cm}^{-3}$) layers grown on an n-type epilayer ($N_D = 5 \times 10^{15} \text{ cm}^{-3}$) with a thickness of 12 μm. Prior to the metal deposition, the SiC samples were degreased in organic solvents followed by standard RCA cleaning. 2 μm height TLM mesas were defined by a SF₆/O₂ reactive ion etching transfer through a 400nm thick Ti/Ni hard metal mask deposited by electron beam evaporation. The residual metal mask was removed by wet etching. Finally, electron beam deposited Ni,Ti,Al,Pt TLM metal patterns were obtained by a lift-off procedure. The chamber pressure before depositing was as low as 5×10^{-7} Torr. Various metal combinations were attempted (see Table 1 for details).

The patterned samples were annealed in argon ambient at temperatures ranging from 700 to 1000°C during 90s in a RTA JIPELEC furnace with a graphite holder using a two steps-based thermal procedure. The first step was made at a relatively low temperature, 350°C, to favor the intermixing between the metallic layers. Therefore, in the second step, the temperature was increased with a rapid heating ramp (up to 50°C/s) to complete the ohmic contact with the p-type SiC layer. Prior to metal annealing, the furnace was cleaned with successive vacuum purges.

The electrical properties of the contacts were tested using I-V current/voltage measures. The specific contact resistances were extracted from TLMs structures, with $80 \times 500 \mu\text{m}^2$ rectangular pads spaced of 25, 35, 45, 55, 65 and 75 μm. We use TLM patterns presenting wide pads close to the mesa etching limit to neglect the transverse current and to obtain a one-dimensional current.

To complete our study, the ohmic contacts were analyzed by Secondary Ion Mass Spectrometry (SIMS) with a CAMECA IMS 4F and Energy-Dispersive X-Ray (EDX) spectroscopy with a Philips CM120 SEM before and after annealing. Identification and following of the profile evolution of constituting element in the contacts and at the SiC/contact interface have been performed.

Results and discussion

Alloyed contacts were produced by depositing thin metal layers and intermixing them into SiC during the high-temperature anneal. Ni/Ti/Al-based metal compositions were investigated by depositing first nickel, then titanium and aluminium with and without capping of nickel, on the p-type SiC epilayer. Additionally, two complementary structures made of Ti/Al/Ti/Pt/Ni and Ti/Al/Ti/Ni were fabricated.

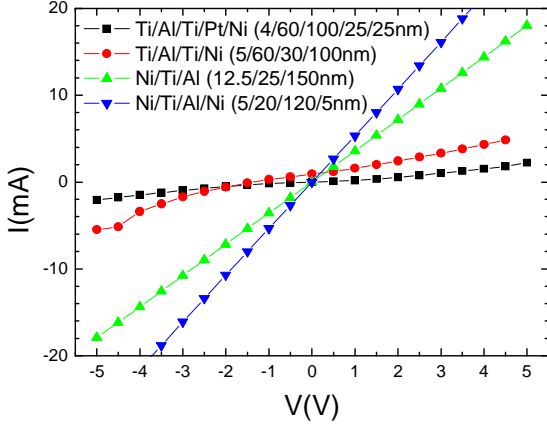


Fig.1. I-V characteristics of the contacts for the four different alloys after 90s annealing at 800 °C.

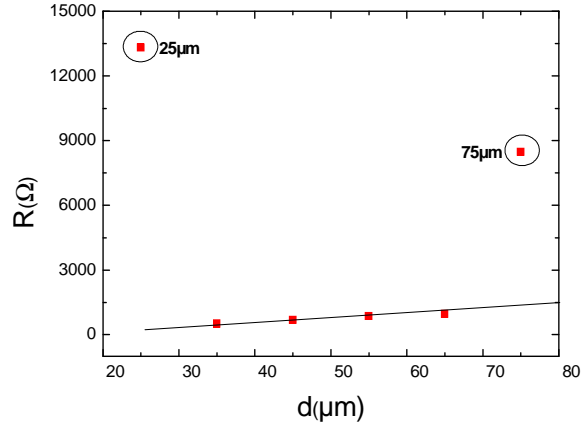


Fig.2. Resistance vs distance between TLM pads of the Ni/Ti/Al contacts after 90s annealing at 800 °C.

For the compositions Ti/Al/Ti/Ni and Ti/Al/Ti/Pt/Ni, I-V curves after annealing are not linear indicating the non-ohmic properties for such contacts (Fig. 1). Even though the relationship in work function between Pt and p-type SiC seems to be well adapted [8], the addition of this metal in the Ti/Al/Ti/Ni contact had no effect on the formation of the ohmic contact.

For all temperatures of annealing, we have noted the presence of an on-surface insulating layer for Ni/Ti/Al metallic contacts. This makes difficult to well characterize these contacts without an adding mechanical ‘scratch’ of the surface. This is the reason we do not obtain a linear variation of the resistance between the TLM metal patterns with the distance between them, despite the ohmic contacts we achieved (Fig. 2). At this point we suggested that this could be due to the oxidation of the last aluminium layer. To protect the easy oxidation, Ni covering was carried out.

Annealing Ni/Ti/Al/Ni and Ni/Ti/Al contacts at temperature as low as 700°C has resulted in a linear I-V characteristic (Fig. 1), indicating that the contact became ohmic. From these results we can conclude on the necessity of the Ni presence at the SiC interface in order to form ohmic contacts.

Finally the dependence of the specific resistance of Ni/Ti/Al/Ni contacts as a function of the final annealing temperature was analyzed (Fig. 3). This was observed to decrease from $2.7 \times 10^{-4} \Omega \text{cm}^2$ at 700°C to a minimal value of $1.5 \times 10^{-5} \Omega \cdot \text{cm}^2$ at 800°C, then increasing for upper temperatures leading also to a deterioration of the ohmic properties. An almost constant sheet resistance of the p-type layer, between 2.7 to 3.3 k Ω/\square , was determined from these TLM measurements.

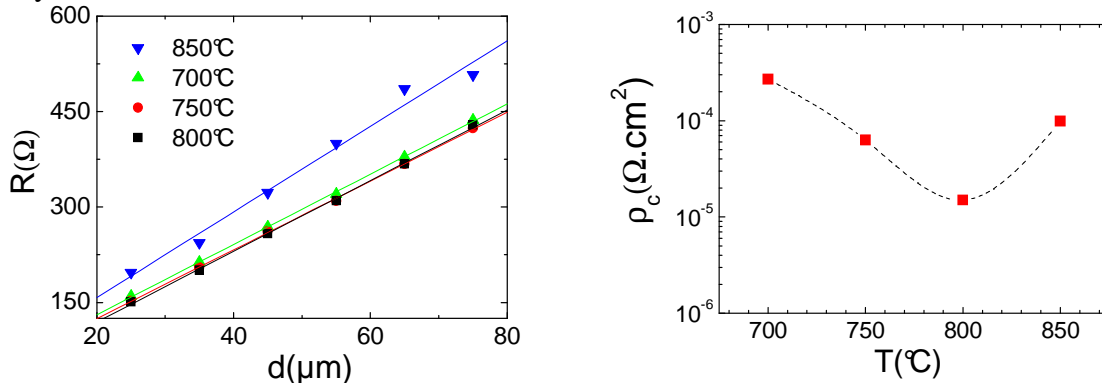


Fig.3. Resistance extracted versus distance between TLM pads of the Ni(10)/Ti(40)/Al(240)/Ni(10nm) contacts and dependence of the specific contact resistance from annealing temperatures at 700 to 850°C

Like for the Ni/Ti/Al contacts we had an insulating layer formed on the edges of the TLM metal electrodes for Ni/Ti/Al/Ni samples, when the quantity of Ni was insufficient (samples with 5nm of Ni – Table 1). At the edge of the TLM electrodes the Ni superficial layers is torn out during the lift-off process. This is probably due to the geometry sides of the photoresist close to the mesa that does not allow a well covering of the Al layer by a too thin Ni layer during e-beam evaporation. This makes difficult the I-V measurements with the extreme TLM electrodes.

Overall with the Ni/Ti/Al/Ni structures we noticed a reproducibility of the 80 % in terms of ohmic contacts obtained without an insulating-resistive layer on surface. Therefore, physico-chemical studies are led to identify the chemical composition of the formed contact layers and especially for this insulating layer.

The interfacial reactions between metals and SiC have been analysed by SIMS. The results of the SIMS profile of the metallic Ni(5nm)/ Ti(20nm)/ Al(120nm)/ Ni(5nm) stacking layers before the annealing are given in Fig. 4a. We can clearly see each metal element from the top to the SiC interface corresponding to their respective deposited position.

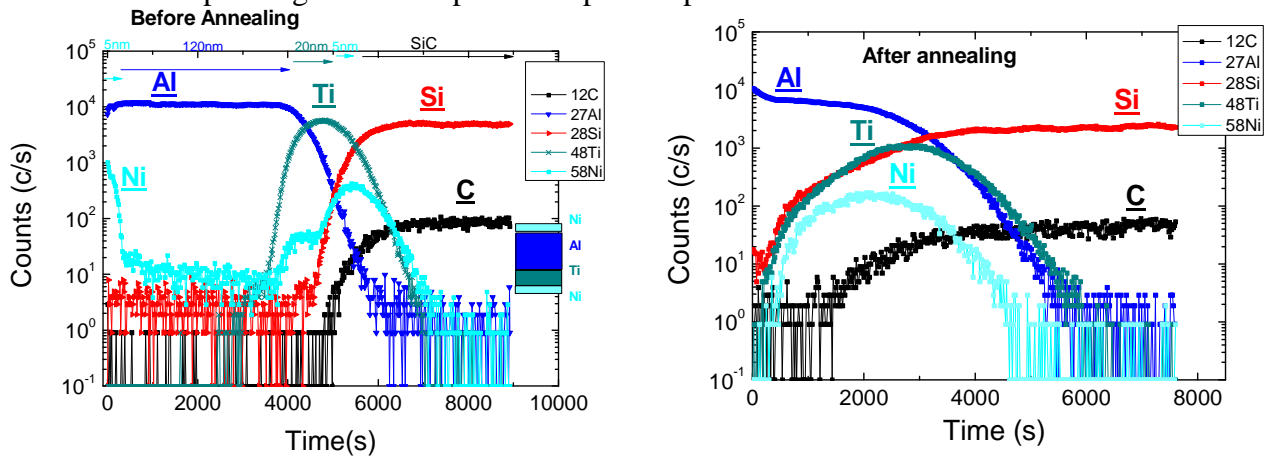


Fig. 4: SIMS spectra for measurements a) before and b) after annealing of Ni/Ti/Al/Ni-4H-SiC sample.

The RTA process leads to the intermixing of the metals with the formation of Al-enriched zone close to the top surface and an interacting zone close to the SiC interface where Ti, Ni, Si and C have diffused leading probably to the formation of Ni_2Si , TiC and Ti_3SiC_2 alloys favouring the ohmic property. We note the absence of a carbonic layer at the SiC interface which is often reported to be responsible for the high values of the specific ohmic contact resistivity (Fig. 4b). The absence of unreacted interfacial carbon atoms must be correlated with the presence of the Ti which is a key-element with a significant diffusion both towards the surface and the SiC interface. Compared to the results presented by Vassilevski et al [6], profiles of Ti and C that we obtained are not correlated. We therefore suppose that Ti_3SiC_2 ternary phase have been formed instead of TiC . As mentioned by Johnson et al [7] Ti_3SiC_2 ternary phase presents a significant effect in the formation of ohmic contact to p-type SiC by forming a narrow-gap interfacial alloy reducing the Schottky barrier height at the metal-SiC interface. Moreover, our results show how important the presence of the Ni at the metal-SiC interface can be for the formation of stable and reliable ohmic contacts.

As we utilized oxygen as primary source during SIMS measurements, complementary analyses were performed using EDX. Results are given in Table 2 before and after annealing. It was found that the contact layer presents an important amount of 20 at% of O_2 only after annealing and not before, meaning that the annealing process did significantly changed the amount of oxygen introduced into the films. This incorporation is still not well understood in our RTA equipment and seems to be dependent of the presence of Al layer since O_2 proportion is increasing from 20 at% to 30 at% with the increasing of the Al thickness from 120 to 300 nm. This oxygen presence did not influence the ohmic property of the Ni/Ti/Al/Ni contacts. This should indicate that it would be a surface-limited reaction with Al only, ohmicity being due to Ni and Ti deeper interaction with SiC interface. Thus rather it would be necessary to increase the thickness of the covering Ni layer on surface which in priori does not really play a role in the formation of the ohmic contact.

		C	O	Al	Si	Ti	Ni
Before annealing	w%	8.82	0.00	34.86	39.83	1.00	15.49
	at%	19.70	0.00	34.65	38.02	0.56	7.07
After annealing	w%	8.06	13.56	34.49	35.95	0.00	7.93
	at%	15.93	20.12	30.35	30.39	0.00	3.21

Table 2: EDX results after annealing Ni(5nm)/Ti(20nm)/Al(120nm)/Ni(5nm) 4H-SiC sample.

Summary

After an examination of four different alloys it is certain that only Ni/Ti/Al/Ni and Ni/Ti/Al alloys, produce ohmic contacts on doped p-type SiC with $N_A=3 \times 10^{19} \text{ cm}^{-3}$. Annealing at temperature in the range 700–800°C results in an ohmic behaviour and a deterioration of the contacts is observed for higher temperatures. The lowest contact resistivity of $1.5 \cdot 10^{-5} \Omega \text{ cm}^2$ has been achieved after annealing at 800°C during 90s in argon atmosphere.

The results of this study show a double role of the Nickel: addition into the contact composition in at the interface is needed to obtain ohmic contacts and in surface to avoid the formation of the insulating layers. Carbonic layer is not present at the metal-SiC interface which is often reported to be responsible for the high values of the specific ohmic contact resistivity. This shows also the role of Ti at interface to prevent the formation of unreacted interfacial carbon atoms. The addition of Pt had no effect on the formation of the ohmic contact.

Overall with the Ni/Ti/Al/Ni structures we noticed a reproducibility of the 80 %, in terms of ohmic contacts obtained without an insulating-resistive layer on surface. From EDX analyses a large amount of oxygen in all the contacts was obtained and this may explain the only 80% reliability yield result. To improve this yield the thickness of the Ni layer on surface must be increased especially at the mesa edge proximity.

Acknowledgements. The authors wish to thank J. Hassan and A. Henry from Linkoping Universitet for epitaxial growth, Ch. Dubois from INL laboratory for SIMS analysis, D. Carole and S. Berckmans from LMI laboratory for EDX analysis and the ANR for the financial support.

References

- [1] J.A. Cooper, M.R. Melloch, J.M. Woodall, J. Spitz, K.J. Schocn: Mater. Sci. Forum 264-268 (1998), p. 895
- [2] F. Roccaforte, F. La Via, V. Raineri: Int. J. High Speed Electron. Syst. 15 (4) (2005), p. 781
- [3] Jae Hyun Parka, Paul H. Holloway: J. Vac. Sci. Technol. B 23.2 (2005), p. 486
- [4] I.P. Nikitina, K. V. Vassilevski, N. G. Wright, A. B. Horsfall, A. G. O'Neill, C.M. Johnson: Journal of Applied Physics 97 (2005), p. 083709.
- [5] R. Konishi, R. Yasukochi, O. Nakatsuka, Y. Koide, M. Moriyama, M. Murakami: Mater. Sci. Eng. B 98 (2003), p. 286
- [6] K. Vassilevski, K. Zekentes, K. Tsagaraki, G. Constantinidis, I. Nikitina: Mater. Sci. Eng. B 80 (2001), p. 370
- [7] B.J. Johnson, M. A. Capano: Journal Of Applied Physics 95 (10) (2004), p. 5616
- [8] J. Crofton, L.M. Porter, J.R. Williams: Phys. Stat. Sol (b). 202 (1997), p. 581
- [9] A. Scorzoni, F. Moscatelli, A. Poggi, G.C. Cardinali, R.Nipoti: Mater. Sci. Forum 457-460 (2004), p. 881.
- [10] J. Crofton, S.E. Mohny, J.R. Williams: Solid-State Electronics 46 (2002), p 109
- [11] H.S.Lee, M.Domeij, C.M.Zetterling, M.Östling, J.Lu: Mater. Sic. Forum 527-529 (2006),p.887
- [12] L.M. Porter, R.F. Davis, Mater. Sci. Eng. B 34 (1995), p. 83
- [13] M. Soueidan, M. Lazar, D.M. Nguyen, D. Tournier, C. Raynaud, D. Planson: Mater. Sci. Forum 615-617 (2009), p. 585
- [14] A. Parisini, A. Poggi and R. Nipoti : Mater. Sci. Forum 457-460 (2004), p. 837