Ni-Al Ohmic contact to p-type 4H-SiC

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H. Vang[a,b], M. Lazar[a], P. Brosselard[a], C. Raynaud[a], P. Cremillieu[c], J.-L. Leclercq[c], J.-M. Bluet[d], S. Scharnholz[b], D. Planson[a]

[a] Centre de Génie Electrique de Lyon, INSA Lyon, Villeurbanne, France
[b] Institut Franco-allemand de Recherches de Saint-Louis (ISL), Saint-Louis, France
[c] Laboratoire Electronique Optoélectronique et Microsystème, EC Lyon, Ecully, France
[d] Laboratoire de Physique de la Matière, INSA Lyon, Villeurbanne, France

Abstract:

Investigations on Ni-Al alloys to form ohmic contacts on p-type 4H-SiC are presented in this paper. Several ratios of the Ni/Al contact were examined. Rapid thermal annealing was performed in Argon atmosphere at 400°C during 1 minute, followed by an annealing at 1000°C during 2 minutes. In order to extract the specific contact resistance, transmission line method (TLM) test-structures were fabricated. A specific contact resistance of 3×10^{-5} Ω.cm^2 was obtained reproducibly on p-type layers, with a doping of $N_A = 1\times10^{19}$ cm^{-3} performed by Al^{2+} ion implantation. The lowest specific contact resistance value measured was 8×10^{-6} Ω.cm^2.

Introduction

Silicon carbide is a semiconductor which has several superior properties with respect to silicon such as a wide bandgap three times greater, a high electric field strength (six times), a high thermal conductivity as good as copper and a high electron saturation drift velocity. Since SiC single-crystal growth wafers were commercialised, intensive investigations have been performed in SiC applications [1] for high temperature, high frequency, and high power devices.

Semiconductor device parameters that control the switching speed and power dissipation depend strongly on the contact resistance [2]. To manufacture high performance SiC devices, development of low resistance ohmic contacts is one of the key issues. It is currently limiting the performances of SiC devices particularly because of contacts to p-type material [3-7]. These contacts employ generally an aluminium-based alloy [3, 7]. Many different solutions have been investigated and a great deal of attention has been focused on Ti/Al [3-5], which has produced specific contact resistances in the range of 10^{-4} - 10^{-5} Ω.cm^2 on p-SiC. Recent attempts to produce improved contacts by using alternative materials such as TiC [6] have resulted in specific contact resistances lower than 1×10^{-5} Ω.cm^2, but these contacts have required "exotic" materials and non standard fabrication techniques. In another hand, some investigations were focused on the contact Ni/Al [7, 8], the advantage is the formation of an ohmic behaviour whatever the composition.

In this paper, the formation of the Ni/Al ohmic contact on p-SiC is presented and discussed through the different parameters. A set of samples was realized with different parameters. Kind attention was first focused on the surface preparation and especially with or without oxidation. Then, the specific resistance versus the Al content in the contact is investigated and discussed. Finally, the effect of the annealing sequence is analysed too. A standard trapezoidal thermal treatment profile is used for the annealing at 1000°C and then modified by the addition of an intermediate step at 400°C for 1 minute.

Experimental

The samples are 4H-SiC n-type substrates with an n-type epilayer doped at 10^{15} cm^{-3} purchased from CREE Research. The p-type regions were obtained by Al^{2+} ion implantation with a concentration $N_A = 1\times10^{19}$ cm^{-3}. The post-implantation annealing was performed at 1650°C during 45 minutes under argon ambient [9]. Samples were first cleaned in solvents then followed by a "piranha" solution. After rinsing, a RCA cleaning is applied to the samples, then they were dipped into buffer oxide etch (BOE). Immediately after the cleaning, a SiO_2 layer was grown in dry oxygen at 1150°C for 2 hours. Lithography was processed to define the transmission line method (TLM) patterns and the oxide was opened just before introducing the samples into the evaporation chamber. The contact composition of Ni followed by the Al was deposited by resistance heating. The TLM contacts were finally obtained by a lift-off process. The formation of the ohmic contact is established only after the annealing which is performed in a RTA furnace under argon atmosphere at 1000°C during few minutes.

Results and discussion

The samples were realized according to different parameters such as the surface preparation, the annealing sequence and the contact composition. In any case, an ohmic behaviour is observed. The specific resistance was extracted from TLM structures. The samples were tested with a probe station and the I(V) measurements were performed with a Source-Meter Unit Keithley 2410.
The results of the specific resistance extracted from the TLM structures on the samples are presented in the table 1. The values are in the range 7.3×10^{-3} – 7.9×10^{-6} $\Omega.cm^2$. Thus, the lowest specific resistance (sample 6) was obtained only once but not with the optimal configuration which gives a reproducible contact resistance of about 3×10^{-5} $\Omega.cm^2$ (sample 3 and 4). The optimal process is established for an oxidation surface preparation and a contact composition of 87 at% Al content.

Surface preparation

Attentions were first carried out on the surface preparation. All the samples were cleaned with the same chemical solutions and then only the sample #5 has not been oxidised. The well effect of the oxidation is demonstrated through the results of the two compared preparations. Samples #4 and #5 have got the same metallization composition with 87 at% of Al content. The sample with oxide exhibits a specific resistance of 2.8×10^{-5} $\Omega.cm^2$ while the sample without oxidation preparation is one order of magnitude greater with a value of 5.6×10^{-4} $\Omega.cm^2$. As the oxide was etched just before the evaporation, the surface was protected by this layer and this prevented the surface from less contamination. The other influence of the oxidation is also the breaking of the Si-C bound during the oxidation, Si atoms react with the oxygen atoms to form the oxide and the carbon atoms react also with the oxygen atoms into CO or CO_2 volatile species [10]. But this phenomenon creates also some carbon clusters at the interface [11] that enhances the beginning of the reactions between the SiC and the metals atoms.

Metallization composition

The metallization is based on the nickel and the aluminium. The composition changed with the increase of the Al content in the contact. The specific resistance obtained in function of the Al content in the metallization is shown graphically in Fig. 1. With an Al content of 73 at% (sample 1), the specific resistance extracted is 7.3×10^{-3} $\Omega.cm^2$ while in the case of higher Al content, the ohmic contact resistance is one order of magnitude lower with 84 at% (sample 2) and two orders of magnitude lower with 87 at% (sample 4). The specific resistance values are 1.84×10^{-4} and 2.8×10^{-5} $\Omega.cm^2$, respectively. The higher Al content in the contact, the lower is the contact resistance.
The presence of Al atoms is compulsory to obtain an ohmic behaviour (sample 9). The increasing of Al atoms causes more reactions with C atoms to form Al_4C_3 alloy [8]. This creates important carbon clusters that facilitate the formation of the Ni_2Si alloy. As mentioned in several works [7, 8], the higher concentration of the Ni_2Si in the contacts, the lower is the specific resistance.
The advantage of the Ni/Al contact compared to the Ti/Al contact is the possibility to get an ohmic behaviour whatever the concentration of Al in the contact. And with the Ti/Al composition, the ohmic behaviour is very sensitive to the Al concentration [3]. The performances of the Ni/Al contacts are as well as the Ti/Al contacts realised in other works on p-SiC ohmic contacts [3-5].

Annealing

In all the investigations on SiC ohmic contacts, a high temperature annealing at 1000°C is necessary to form a good ohmic contact even for contacts on n-type layers [12]. This temperature is needed to cause reaction between the SiC and the metals at the interface. Here, because of the contact composition with an aluminium layer on the top, a rapid ramp to 1000°C is required to avoid evaporation. A ramp superior to 50°C/s is preferred; the fast arrival of thermal energy brings rapidly reactions between the Al and the Ni or the C atoms and then limits the evaporation. Two configurations were performed. The first one is a standard process, with a rapid ramp to 1000°C and an annealing during 2 minutes before cooling. The second begins with a first stage at 400°C during 1 minute followed by a step at 1000°C during 2 minutes (fig. 2).
The sample #7 was annealed with the first configuration and the sample #8 with the second temperature profile. Sample #7 and #8 show a specific resistance of 5.6×10^{-3} and 4.5×10^{-5} $\Omega.cm^2$ respectively. In the second case, the ohmic contact is two orders of magnitude lower than the first one. It could be assumed by the fact that during the step at 400°C, AlNi alloys are formed and are stable at high temperature and limits the evaporation of aluminium. Profilometry measurements after the annealing demonstrated a contact thickness reduction of 25 % and less than 10 % for the two profiles respectively. Thus, more Al atoms could react with C atoms from the SiC to enhance the formation of Ni_2Si alloy which is predominant in the formation of the ohmic contact.

Conclusion

In this work, a Ni/Al ohmic contact to p-type 4H-SiC was developed. After optimization of the process through the surface preparation, the contact composition and the annealing, a reproducible ohmic contact with a specific resistance of $3\times10^{-5}\ \Omega.cm^2$ was demonstrated on a p-type layer doped at $10^{19}\ cm^{-3}$. This result is obtained with an oxidation surface preparation to protect the surface until metals are deposited. The contact composition is a nickel layer of 50 nm thick and an aluminium layer of 500 nm thick which represents 87 at% of the contact. After the annealing at 400°C for 1 minute followed by another step at 1000°C during 2 minutes, the ohmic contact becomes effective.
Further characterizations will be done in high temperature to check the stability of the contact in order to validate this process as a possibility for the ohmic contacts formation of SiC devices working at high temperature.

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Table 1. Summary of specific resistances from the samples.

Sample	Ref.	N_A (cm-3)	Composition Ni (nm)	Al (nm)	Al content (at%)	Oxyd.	Annealing Temp. (°C)	Duration (s)	ρ_c (Ω.cm^2)
1	R0321-7 n°29	10^{19}	50	200	73	yes	1000	120	$7,3\times10^{-3}$
2	DC20C2-23-SY-7	10^{19}	50	400	84	yes	1000	120	$1,85\times10^{-4}$
3	CN – B	10^{19}	50	500	87	yes	1000	120	$3,2\times10^{-5}$
4	CN – C	10^{19}	50	500	87	yes	1000	120	$2,8\times10^{-5}$
5	CN – D	10^{19}	50	500	87	no	1000	120	$5,6\times10^{-4}$
6	DC20C2-23-SY-8	10^{19}	50	400	84	yes	1000	120	$7,9\times10^{-6}$
7	R0321-7 n°28	10^{19}	50	450	86	yes	1000	120	$5,6\times10^{-3}$
8	CN – A	10^{19}	50	450	86	yes	1000	120	$4,5\times10^{-5}$
9	FL0288-10 n°2	10^{19}	50	0	0	yes	1000	120	not ohmic

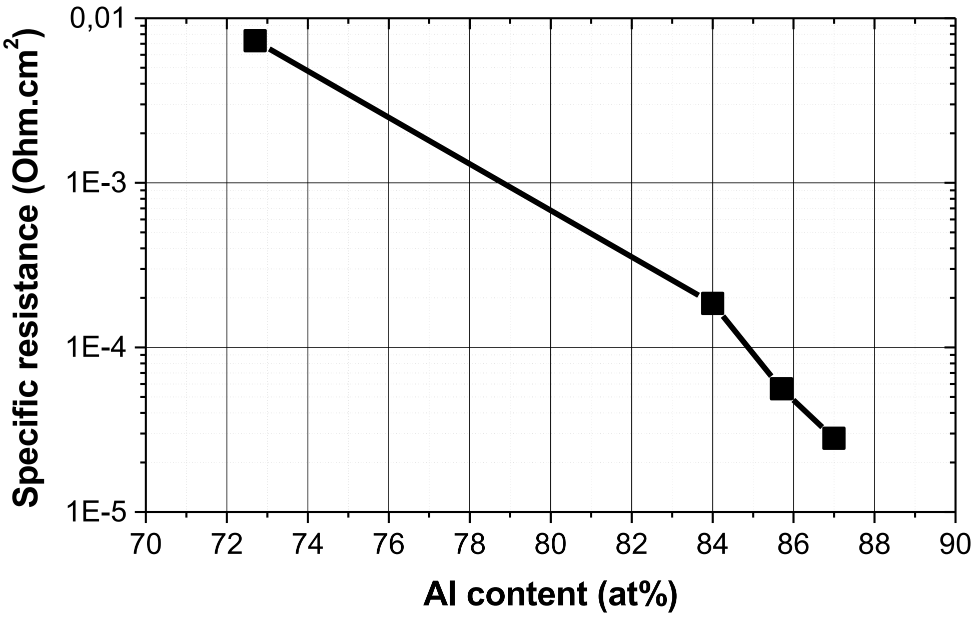

Figure 1. Specific resistance versus the Al content in the contact.

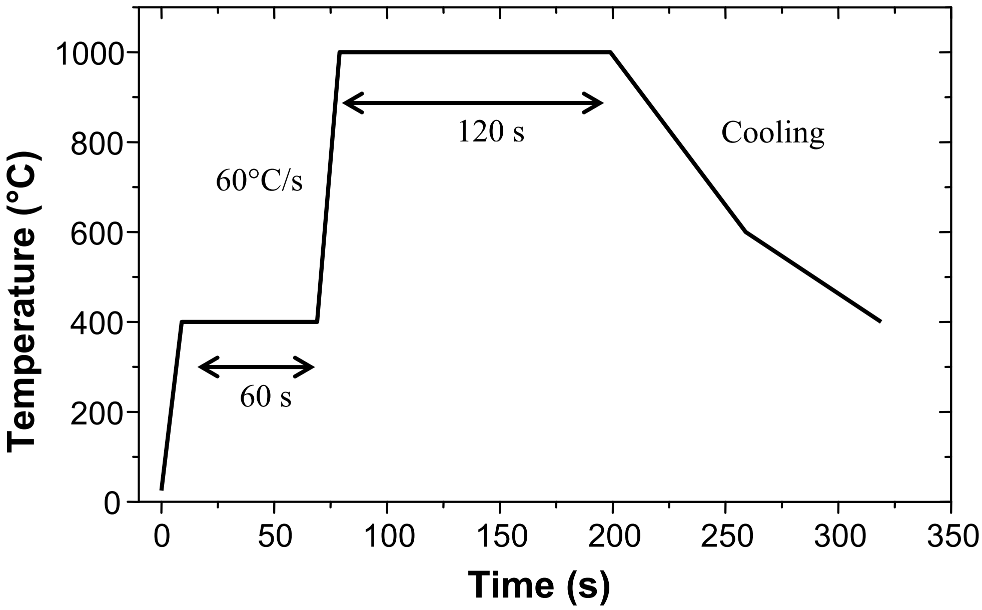

Figure 2. Annealing profile