Study on Co- and Ni-base Si_2 for SiC ohmic contact

Chang Kyo Kim*, Seong Joon Yang*, Il Ho Noh*, Seok Won Jang*, Nam In Cho**, Jeong Kyoung Hwa**

Abstract

We report the material and electrical properties of $CoSi_2$ and $NiSi_2$ contacts to n-type 4H-SiC depending on the post-annealing and the metal covering conditions. The Ni and Co silicides are deposited by RF sputtering with Ni/Si/Ni and Co/Si/Co films separately deposited on 4H-SiC substrates. The deposited films are annealed at 800 ℃ in Ar:H_2 (9:1) gas ambient. Results of the specific surface resistivity measurements show that the resistivity of the Co-based metal contact was the one order lower than that of the Ni-based contact. The specific contact resistance was measured by a transmission line technique, and the specific contact resistivity of 1.5×10^{-6} Ωcm^2 is obtained for Co/Si/Co metal structures after a two-step annealing; at 550 ℃ for 10 min and 800 ℃ for 3min. The physical properties of the contacts were examined by using XRD and AES, and the results indicate that the Co-based metal contacts have better structural stability of silicide phases formed after the high temperature annealing.

Key Words : Silicon carbide (SiC), Ohmic contact, TLM(Transmission Line Model), contact resistivity(ρ_c)

1. Introduction

A wide band gap semiconductor, silicon carbide (SiC), is of great interest for the high power control and high-speed communication devices because of the high breakdown field strength and the high saturation velocity of electron [1]. Especially, 4H-SiC is the expected material for these devices because it has the high electron mobility and the wide band gap in comparison with the other SiC single crystals such as 6H-SiC. The structural and electrical properties of the ohmic contact are of importance on the operation of electron devices such as metal-semiconductor field-effect-transistors (MESFETs) and metal-oxide-semiconductor field-effect-transistors (MOSFETs). The poor ohmic contact may produce a problem that led to a device of limited performance and reliability. Co and Ni contact structures have been widely studied for the ohmic contact of n-type SiC [2-3]. Although the Co and Ni contacts show the ohmic characteristics, the Co and Ni contacts have the structural problems in contact layer [4-5]. As reported in literatures [2-5], the Co and Ni contacts usually contain graphite-state C atoms in the produced layer and the large voids have also been observed in the vicinity of the interface in the produced layer. Since the Co and Ni contacts include the structural fluctuation

* : Soonchunhyang University, Korea
(Shinchang-myun, Asan-si, Chungnam 646 R.O. Kor)
Fax : 041-530-1097
E-mail : ckkim1@sch.ac.kr
** : Sunmoon university, Korea

such as voids, the contacts would show a poor reliability for electrical properties. To reveal and improve the ohmic characteristics for the Co and Ni contacts, Co-silicide and Ni-silicide must be synthesized in the contact layer by the direct reaction between Co, Ni and the SiC substrate [6-9]. Since $CoSi_2$ and $NiSi_2$ are the Si-rich phase in Si-Co and Ni system, the abrupt $CoSi_2$ and $NiSi_2$ / 4H-SiC interfaces are formed without the dissociation of SiC by annealing for separately deposited Co, Ni and Si films. Therefore, $CoSi_2$ and $NiSi_2$ contact includes no void without the direct reaction between the contact material and the substrate. In this paper, we report the structural and electrical properties of $CoSi_2$ and $NiSi_2$ contact formed on n-type 4H-SiC.

2. Experimental

The Co- and Ni-based ohmic contacts were made on n-type homoepitaxial layer with a thickness of 10 mm and a donor concentration of $1.1\times10^{19}cm^{-3}$ grown on (0001) Si-face 4H-SiC substrates. The epitaxial layer has a resistivity of 0.007 Ωcm and a thickness of 398 ㎛. Before making the metal contacts, the 4H-SiC substrates were cleaned by Huang cleaning method. The Huang cleaning method is well known technique for the SiC semiconductor using chemical solutions of $NH_4OH:H_2O_2:H_2O$ = 1:1:5 at 75 ℃ for 10 min and HCl: $H_2O_2:H_2O$ = 1:1:5 5 at 75 ℃ for 10 min, followed by buffered oxide etching solution with deionized water rinse after each step. The cleaned SiC substrates were put to the sputtering chamber, and RF sputter deposited to make are Co/Si/Co and Ni/Si/Ni structures. Si (50 nm in thickness) and Co (100, 150 nm) films were deposited on (0001) Si-faced substrate by means of RF sputtering system in a base vacuum of the order of 10^{-7} Torr. Si (50 nm in thickness) and Ni (100, 150 nm) films were also deposited with the same method. The metal (Co or Ni) and silicon thicknesses have to be designed to produce the stoichiometric $CoSi_2$ and $NiSi_2$ alloy. The Co/Si/Co and Ni/Si/Ni films deposited on SiC substrate were annealed at 55 0℃ for 10min, followed by 800℃ for 3min in a flow of Ar gas containing 10 vol.% H_2 gas using a conventional furnace with a sealed tube to avoid the oxidation of the samples.

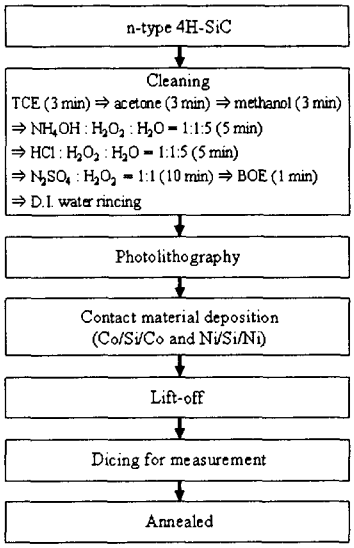

Fig 1. Flow diagram of sample preparation.

Fig. 1 shows a flow diagram of the sample preparation sequence. Measurements of current-voltage (I-V) characterizations were performed using a HP4145 (semiconductor parameter analyzer) combined with a micro-probe equipment at room temperature. The contact resistances of $CoSi_2$ and $NiSi_2$ contacts (contact dimension 50×50 $㎛^2$ in area and contact spacing 10, 20, 30, and 90 ㎛) on the SiC substrate with n = $1.1\times10^{19}cm^{-3}$ were evaluated using transmission line method (TLM). The SEM micrograph of the TLM pattern made in the present experiment is shown in Fig. 2.

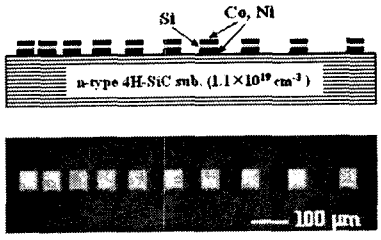

Fig 2. SEM micrograph of TLM pattern.

3. Result and Discussion

The specific contact resistivity of the Co- and Ni-based contacts on SiC was measured by TLM techniques. To determine the specific contact resistance (ρ_c), total resistances (R_t) obtained from I-V characteristics were plotted as a function of contact spacings.

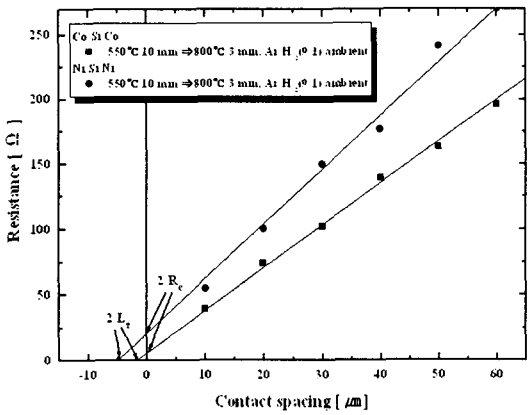

Fig 3. Plot of the total resistance versus the contact spacing for $CoSi_2$ and $NiSi_2$ contacts formed on n-type 4H-SiC

Fig. 3 shows the plots of measured R_t versus the contact spacing for $CoSi_2$ and $NiSi_2$ contacts formed on the SiC substrate with n = $1.1\times10^{19}cm^{-3}$. The contact resistance (R_C) and the transfer length (L_T) were estimated to be 2 Ω and 1.5 μm for $CoSi_2$, 9.5 Ω and 2.5 μm for $NiSi_2$ contacts, respectively. The ρ_c was calculated from the plots, and estimated as 1.5×10^{-6} cm^2 for $CoSi_2$, $1.4\times10^{-5}cm^2$ for $NiSi_2$ contacts, using the equation of ρ_c = contact × R_C × L_T.

L_T [μm]	1.5	2.5
R_C [Ω]	2	9.5
Contact resistivity [Ω - cm^2]	1.5×10^{-6}	1.4×10^{-5}

Table 1. Comparison of specific contact resistivity, transfer length and contact resistance between Co- and Ni-based metal structures.

Table 1 summaries the results of the electrical measurements. Apparently, the result of the electrical properties indicates that the specific contact resistivity of $CoSi_2$ contact is approximately 10 times lower than that of the $NiSi_2$ contact. In order to understand the results of the electrical measurements, the material properties for the Co- and Ni-based contacts on SiC were also investigated by X-ray diffraction (XRD) and Auger electron spectroscopy (AES).

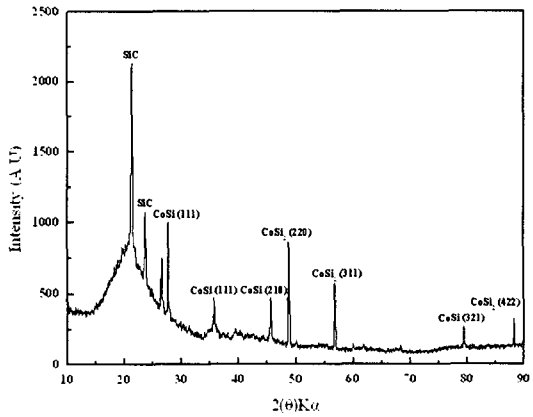

Fig 4. X-ray diffraction scans for $CoSi_2$ contacts formed on n-type 4H-SiC at 500℃/ 10 min, 800℃/ 3min ($Ar:H_2$(9:1) ambient)

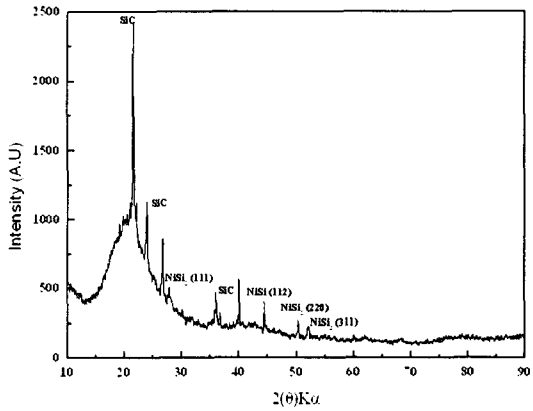

Fig 5. X-ray diffraction scans for $NiSi_2$ contacts formed on n-type 4H-SiC at 500℃/ 10 min, 800℃/3min ($Ar:H_2$(9:1) ambient)

Fig. 4 and 5 shows the glancing angle XRD nature, and the results of the XRD analysis reveal the formation of Co- and Ni-silicide at temperature in the contact layer. Two different phases of Co-silicides, CoSi and $CoSi_2$ are appeared in Fig. 4, but silicon-rich phase $CoSi_2$

is dominated in the XRD. Similar XRD results are obtained for Ni/Si/Ni system as shown in Fig. 5. But the intensity peaks of the Ni-silicides are much lower than those of Co-silicides, which indicates that very little cobalt atoms are left in the layer and an increased amount of $CoSi_2$, whereas the Ni-silicides have a small amount of $NiSi_2$. This agrees with experimental results of Rastagacva et. al. [10-11] and Liu et. al. [12-13], in which the formation of $NiSi_2$ was reported upon annealing. However, these observations contrast with the data of Steckl et. al. [14] who has reported no change in nickel at has reported

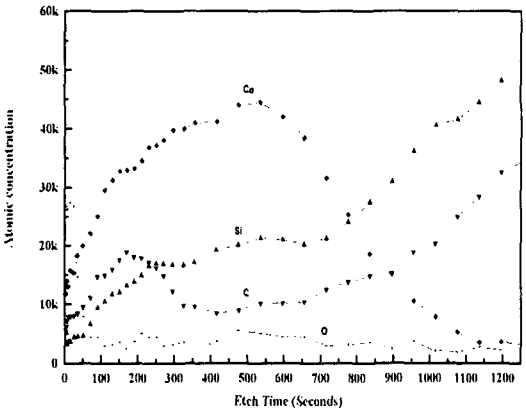

Fig 6. AES depth profile of an Co/Si/Co ohmic contact annealed at 500℃/ 10 min, 800℃/ 3min (Ar:H2(9:1) ambient)

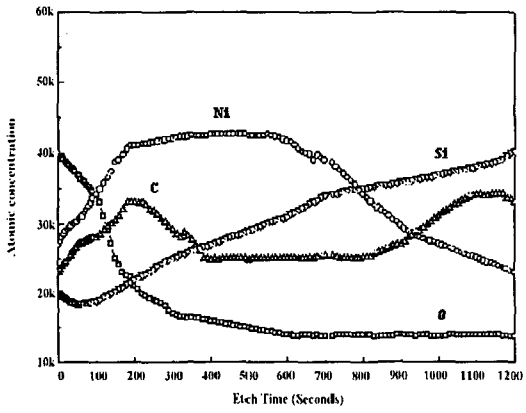

Fig 7. AES depth profile of an Ni/Si/Ni ohmic contact annealed at 500℃/ 10 min, 800℃/ 3min (Ar:H2(9:1) ambient)

no change in nickel at temperatures of up to 600 ℃, but formations of $NiSi_2$ and Ni_5Si_2 phases were detected after the annealing at 900 ℃. Annealing at higher temperatures (>1000 ℃) may be necessary to cause a reaction between Ni and SiC. Fig. 6 and 7 show the AES depth profiles of the Co/Si/Co and Ni/Si/Ni systems, respectively. After the annealing at temperatures of above 800 ℃, reactions at the Co/Si and Ni/Si interfaces formed by the inter-diffusion of the two elements, indicating the onset of $CoSi_x$ and $NiSi_x$ formations, are observed. The solid-state reaction resulted in the virtual disappearance of the Si peak corresponding to the deposited Si layer. In the Co/Si/Co system, the thermal process at 800 ℃ is considered to be enough for the reaction of the Co with the SiC surface as well as with the Si films, which result the uniform inter-mixing of the Co and Si layer as shown in Fig. 6. On the other hand, in the Ni/Si/Ni system, the Si concentration is gradually increased along the depth of the metal layer as seen in Fig. 7. This result indicates that the uniform inter-mixing between Ni and Si films may not be obtained due to the lack of the thermal energy[14].

4. Conclusion

Material and electrical properties of $CoSi_2$ and $NiSi_2$ contacts to n-type 4H-SiC are studied depending on the post-annealing and the metal covering conditions. The Ni and Co silicides are deposited by RF sputtering with Ni/Si/Ni and Co/Si/Co films separately deposited on 4H-SiC substrates. The deposited films are annealed at high temperature of 800 ℃ in Ar gas ambient, and the electrical resistivity of the films was measured by using a semiconductor parameter analyzer. Results of the specific surface resistivity measurements show that the resistivity of the Co-based metal contact is the one order lower than that of the Ni-based contact. The specific contact resistance was measured by a transmission line technique, and the specific contact resistivity of $1.5\times10^{-6}cm^2$ is obtained for Co/Si/Co metal structures after the annealing. The material properties of the contacts

were also examined by using XRD and AES, and the results indicate that the Co-based metal contacts have better structural stability of silicide phases formed after the high temperature annealing. The stable Co-rich silicide, $CoSi_2$ has conjectured to produce the lower electrical resistivity.

References

[1] M. Bhatanagar and B. J. Baliga, IEEE Electron Dev. 40 (1993) 645.

[2] J. Crofton, P. G. McMullin, J. R. Williams, and M. J. Bozack, J. Appl. Phys. 77 (1995) 1317.

[3] T. Uemoto, Jpn. J. Appl. Phys. 34 (1995) 7.

[4] B. Pecz, G. Radnoczi, S. Cassete, C. Brylinski, Diaomond and Related Materials 6 (1997) 1428.

[5] Ts. Marinova, A. Kakanakova-Geirgieva, V. Krastev, R. Kakanakov, M. Nesev, L. Kassamakova, O. Noblanc, C. Arnodo, S. Cassette, C. Brylinski, B. Pecz, G. Radnoczi, and Gy. Vincze, Mater. Sci. Eng. B46 (1997) 223.

[6] N. Lundberg, M. Ostling, Solid State Electronics 39 (1996) 11.

[7] N. Lundberg, M. Ostling, Solid State Electronics 38 (1995) 12.

[8] S. Tanimoto, N. Kiritani, M. Hoshi, H. Okushi, Silicon Carbide and Related Materials 389 (2002) 879.

[9] T. Nakamura, M. satoh, Silicon Carbide and Related Materials 389 (2002) 889.

[10] M. G. Rastegaeva, A. N. Andreev, V. V. Zelenin, I. P. Nikitina, V. E. Chelnokov, and V. P. Rastegaev, Silicon Carbide and Related Materials 53 (1995) 152.

[11] S. Nakashima, H. Matsunami, S. Yoshida, and H. Harima, Inst. Phys. Conf. Ser. 142 (1996) 581.

[12] S. Liu, K. Reinhardt, C. Severt, and J. Scolleld, Silicon Carbide and Related Materials 53(1995) 172.

[13] H. Matsunami, S. Yoshida, and H. Harima, Inst. Phys. Conf. Ser. 142 (1996) 589.

[14] M. G. Speneer, R. P. Devaty, J. A. Edmond, M. Asifkhan, R. Kaplan, and M. Rahman, Inst. Phys. Conf. Ser. 137 (1994) 65.