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# Investigation of Au/Ti/Al ohmic contact to N-type 4H–SiC

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**Abstract**

In this study, investigation on Au/Ti/Al ohmic contact to n-type 4H–SiC and its thermal stability are reported. Specific contact resistances (SCRs) in the range of $10^{-4}$–$10^{-6}$ Ω cm$^2$, and the best SCR as low as $2.8 \times 10^{-6}$ Ω cm$^2$ has been generally achieved after rapid thermal annealing in Ar for 5 min at 800 °C and above. About 1–2 order(s) of magnitude improvement in SCR as compared to those Al/Ti series ohmic systems in n-SiC reported in literature is obtained. XRD analysis shows that the low resistance contact would be attributed to the formation of titanium silicides ($TiSi_2$ and TiSi) and $Ti_3SiC_2$ at the metal/n-SiC interface after thermal annealing. The Au/Ti/Al ohmic contact is thermally stable during thermal aging treatment in Ar at temperature in the 100–500 °C range for 20 h.
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*Keywords:* Ohmic contact; Silicon carbide; Specific contact resistance; Thermal stability

## 1. Introduction

Since silicon carbide (SiC) is a wide bandgap semiconductor which has excellent electrical and physical properties of high breakdown field ($4 \times 10^6$ V/cm), high electron saturation drift velocity ($2 \times 10^7$ cm/s) and high thermal conductivity (4.9 W/cm K) [1–3]. It has received increasing attention for a wide variety of high power, high frequency, and high-temperature devices applications. Recently, successful fabrication of SiC devices including Schottky barrier diodes, p–i–n diodes, metal–oxide–semiconductor field effect transistors (MOSFETs), thyristors, and insulated gate bipolar transistors (IGBTs), etc., and their performance have been demonstrated [4–10].

The very success of SiC devices relies on the realization of robust and low-resistance ohmic contacts to allow for high current driving and keep the power losses of device within reasonable limits. To date, different techniques have been employed to obtain ohmic contacts to 4H–SiC. Efforts including high temperatures annealing, increasing surface doping by ion implantation, and using metal alloys, etc., have been made to reduce contact resistance [11–30]. A survey of contact materials, processing conditions, and specific contact resistances (SCRs) to n- and p-type 4H–SiC reported in the literature is listed in Table 1. It is noted that the most common use of the contact material to n-SiC is Ni which yields SCRs in the $10^{-5}$–$10^{-6}$ Ω cm$^2$ range after annealed at 950–1050 °C [11–14]. For p-type SiC, Ti/Al alloy or silicides have been demonstrated achieving an SCR in the $10^{-4}$–$10^{-5}$ Ω cm$^2$ range after annealed at 900–1180 °C [11,24,26].

Since the work function difference between heavily doped n- and p-type SiC is extremely large (approximate the bandgap of SiC), it is very difficult to form ohmic contact to both p- and n-type material using the same contact metal system. Ni is one of the metals that have been used

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Table 1
A survey of experimental results of ohmic contacts to (a) n-SiC and (b) p-SiC reported in the literature

| Metal | Doping in n-SiC ($cm^{-3}$) | SCR ($\Omega\,cm^2$) | Annealing temperature (°C) | Refs. |
|---|---|---|---|---|
| *Panel (a)* | | | | |
| Ni | $1–10\times10^{18}$ | $2.8\times10^{-3}–2.8\times10^{-6}$ | >950 | [11–14] |
| Ti | $1\times10^{20}$(6H–SiC) | $2\times10^{-5}$ | As-deposited | [15] |
| W | $3\times10^{18}–1\times10^{19}$ | $5\times10^{-3}–1\times10^{-4}$ | 1200–1600 | [16] |
| Mo | $>1\times10^{19}$ | $\sim1\times10^{-4}$ | – | [17] |
| Ta | $>1\times10^{19}$ | $\sim1\times10^{-4}$ | – | [17] |
| Ti–Al | $4.5\times10^{20}$ | $\sim1\times10^{-3}$ | 1000 | [18] |
| TiN | $\sim1\times10^{18}$ | $4\times10^{-2}$ | 600 | [19] |
| TiW | $1.1\times10^{19}$ | $2–6\times10^{-5}$ | 950 | [20] |
| TiC | $1.3\times10^{19}$ | $4\times10^{-5}$ | 950 | [21] |
| TaC | $2.3\times10^{19}$ | $2.1\times10^{-5}$ | 1000 | [22] |
| $CoSi_2$ | $1.1\times10^{19}$ | $1.8\times10^{-6}$ | 500/800 two step | [23] |
| $NiSi_2$ | $1\times10^{19}$ | $1.2–2.7\times10^{-5}$ | 950 | [14] |
| | Doping in p-SiC ($cm^{-3}$) | | | |
| *Panel (b)* | | | | |
| Ni | $1\times10^{15}$ | $1.5\times10^{-4}$ | 1050 Al/C co-ion imp. | [13] |
| Ti/Al | $3–5\times10^{19}$ | $1.42\times10^{-5}$ | 900 | [11] |
| Al/Ti | $1\times10^{19}$ | $6.4\times10^{-4}$ | 900 | [24] |
| Si/Pt | $1\times10^{19}$ | $2\times10^{-4}$ | 1100 | [24] |
| TiC | $2\times10^{19}$ | $1.9\times10^{-5}$ | 500 Al ion imp. | [25] |
| AlSiTi | $3–5\times10^{19}$ | $9.6\times10^{-5}$ | 950 | [26] |
| TiN | $1\times10^{19}$ | $4.4\times10^{-5}$ | FIB deposited at 650 °C | [27] |
| Pd | $5\times10^{19}$ | $5.5\times10^{-5}$ | 700 | [28,29] |
| Au/Ti/Al | $3–5\times10^{19}$ | $1.6\times10^{-5}$ | 950 | [30] |

for ohmic contact to both n- and p-type 4H–SiC. However, the fabrication process for realizing ohmic contact to p-type 4H–SiC using Ni, such as using Al/C co-ion implantation to have a heavily doped p-SiC surface layer [13], still very complicated and the measured SCR was not low enough ($1.5\times10^{-4}\,\Omega\,cm^2$) for device applications due to its low doped ($1\times10^{15}\,cm^{-3}$) n-type SiC substrate. For p-SiC, Al/Ti or Au/Ti/Al ohmic contact systems have been well developed with low SCRs in the $10^{-4}–10^{-5}\,\Omega\,cm^2$ range [11,24,30]. However, reports on ohmic contact to n-SiC using Ti/Al contact system is very limited. The reported SCR of Ti/Al/n-4H–SiC contact system is usually with a relatively higher of around $\sim10^{-3}\,\Omega\,cm^2$ [18]. In this work, an attempt was made to achieve the same Ti–Al-based ohmic contact system as p-type 4H–SiC also to n-type 4H–SiC. Considering the fact that Ti–Al-based contact system usually suffers from serious oxygen contamination, a thin layer of Au was intentionally deposited on the top of the Ti/Al contact to prevent possible oxidation during thermal annealing. Current–voltage characteristics of the contacts before and after rapid thermal annealing at temperatures ranging from 700 to 1050 °C are investigated and discussed. The thermal stabilities of the prepared samples after a thermal aging treatment at 100–500 °C in Ar for 20 h are also reported.

## 2. Experiments

In experiments, n-type 4H–SiC wafers with a low resistivity of 0.017 Ω cm, which corresponds to a doping concentration of the range of $0.8–1.2\times10^{19}\,cm^{-3}$, and with 8° off-axis from (0001) were used. Before metal deposition, the samples were cleaned in acetone, sulfuric acid, and followed by a standard RCA cleaning process. Aluminum (150 nm), titanium (150 nm), and gold (100 nm) were deposited in sequence on the surface of the 4H–SiC wafer using a thermal evaporator under a background pressure around $1\times10^{-6}$ Torr. Metal lift-off process was than performed in acetone to define the contact pattern of samples. Finally, the prepared samples were subjected to a rapid thermal annealing (RTA) at temperatures ranging form 700 to 1050 °C for 5 min in argon (Ar) ambient.

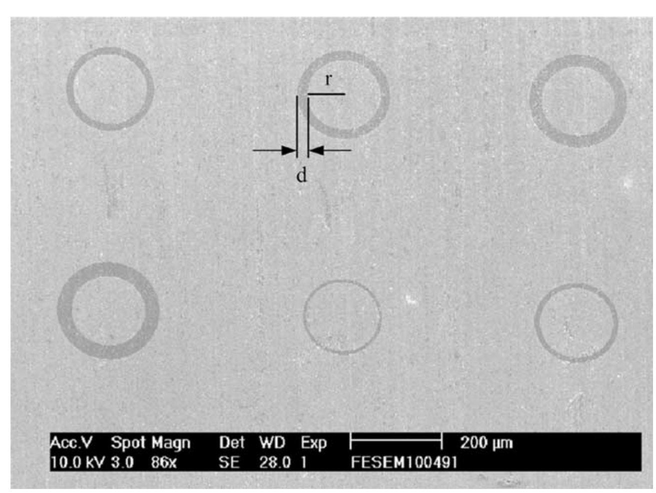


Fig. 1. SEM photograph of CTLM structure of Au/Ti/Al/n-SiC contact systems.

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