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Sputtered Ohmic Cobalt Silicide Contacts to 4H-SiC

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Abstract. Ohmic $CoSi_2$ contacts to n-type 4H-SiC showing low contact resistance have been made by sputter depositing sequential layers of Si and Co on 4H-SiC substrates followed by a two-step rapid thermal anneal at 600 °C and 950 °C. The contacts formed have been characterized at temperatures ranging from -40 °C to 500 °C with a specific contact resistance of $3.8 \cdot 10^{-5}$ Ωcm^2 at 25 °C and a minimum of $6.0 \cdot 10^{-6}$ Ωcm^2 at 500 °C.

Introduction

$CoSi_2$ is of interest for high temperature electronics because it combines high thermal stability with low resistivity. In the literature annealed evaporated $CoSi_2$ contacts have been presented to both 6H- and 4H-SiC with a special success to p-type 6H-SiC [1-3]. Though one of the major interests in using $CoSi_2$ is for high temperature applications, the results earlier presented for 4H-SiC have only been measured at ambient temperature. In order to evaluate the suitability of $CoSi_2$-contacts to SiC in harsh environments, high temperature measurements as well as measurements below zero °C are needed.

$CoSi_2$ is one of the most silicon consuming silicides requiring about 363 nm Si to form out of 100 nm Co. When the silicidation occurs on SiC, the Si consumption from the substrate is associated with carbon release. To minimize the amount of free C several versions of Si addition during the metal deposition have been reported for both Co- and Ni-contacts [1-4].

With access to a high performance sputtering system allowing deposition of very thin layers of well-defined thicknesses, the contacts presented here consist of alternately sputter deposited layers of Si and Co, Fig.1-2, which have been afterwards annealed and characterized. The addition of Si limits the amount of consumed SiC thus the free C, while the stacking facilitates the silicidation process and minimizes the stress between the layers, all in an attempt of an improved substrate/silicide interface.

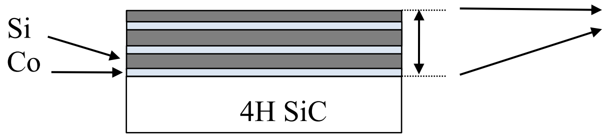

Fig. 1. Schematic of the stacked Co and Si layers.

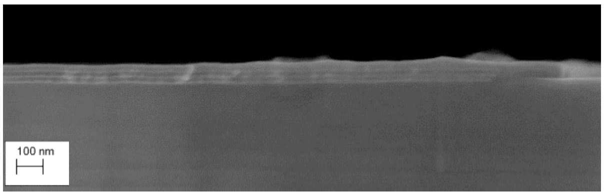

Fig. 2. SEM micrograph of the as-deposited Si/Co-layers (crossection). This sample has a total metallization stack of 60 nm.

Experimental

As seen in table 1, two types of 4H-SiC samples were prepared; substrate chips for annealing tests (type A) and chips with mesa etched epitaxial n- and p-type layers corresponding to an inhouse IC-process [5] for contact resistivity measurements (type B). Samples were cleaned for 5 min in piranha solution (H_2SO_4: H_2O_2 mixed 3:1) followed by a 30 s HF-dip. Lift-off photolithographic patterning was made using LOR 5A and Megaposit SPR 700-1.2 finished with a 5 min O_2 plasma descum step. The samples were then directly mounted in an AJA ATC Orion-8 magnetron sputtering system for metal deposition. A one minute RF back sputtering step was employed for removal of any native oxide. Co and Si layers were sputter deposited starting with Co to SiC and

Table 1. Sample A and B.

Sample	Epitaxial Layers [cm^{-3}]	RTA	Pattern	Metallization [nm]
A	No epitaxial layers.	3·4 min 600 °C, 1+2 min 800 °C, 1 min 950 °C measurements after each	Isolated contacts	SiC/Co/Si/Co /Si/Co/Si 5/15/5/ 15/5/7.5 Thickness ratio Si:Co 2.5:1
B	1 µm $N_D=1\cdot10^{19}$ 1 µm $N_A=1\cdot10^{18}$ 0.5 µm $N_D=2\cdot10^{18}$	4 min 600 °C + 1 min 950 °C in constant N_2 flow	TLM structures on isolated, etched mesas	

ending with a Si-layer half the thickness of the earlier Si layers giving a total thickness ratio of 2.5:1 for Si:Co. DC and RF magnetron sputtering was used for the Co and Si targets respectively, ambient gas for the sputtering was Ar at a pressure of 2.5 mTorr and the power was 150W. Both targets were of purity ≥99.9%. Samples A and B were deposited at the same time and the thicknesses are presented in Table 1.

As annealing is a crucial step in ohmic contact processing to SiC, samples of type A were used only for testing and evaluating the annealing temperatures and times. The samples were annealed at increasing temperatures with measurements and microscopy inspections in-between each step. Since the as-deposited contacts are not conductive within themselves due to the layered structure with Si on top, two types of IV-measurements were performed in the RTA development: between two contacts and with two probes on the same contact. The measurement between contacts show

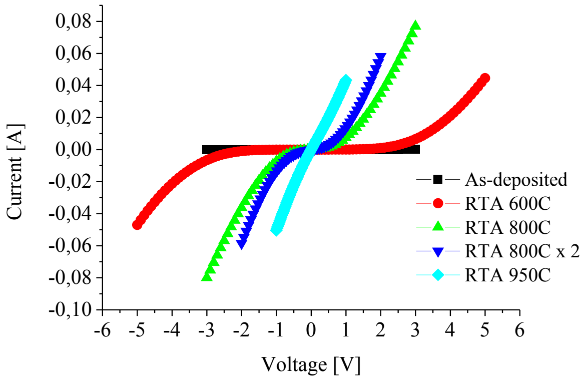

Fig. 3. Samle A. Influence of increasing RTA temperatures to the stacked Co/Si-contacts.

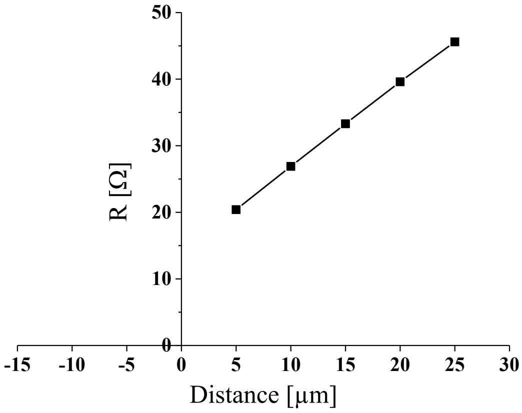

Fig. 4. Sample B. TLM measurement at 25 °C.

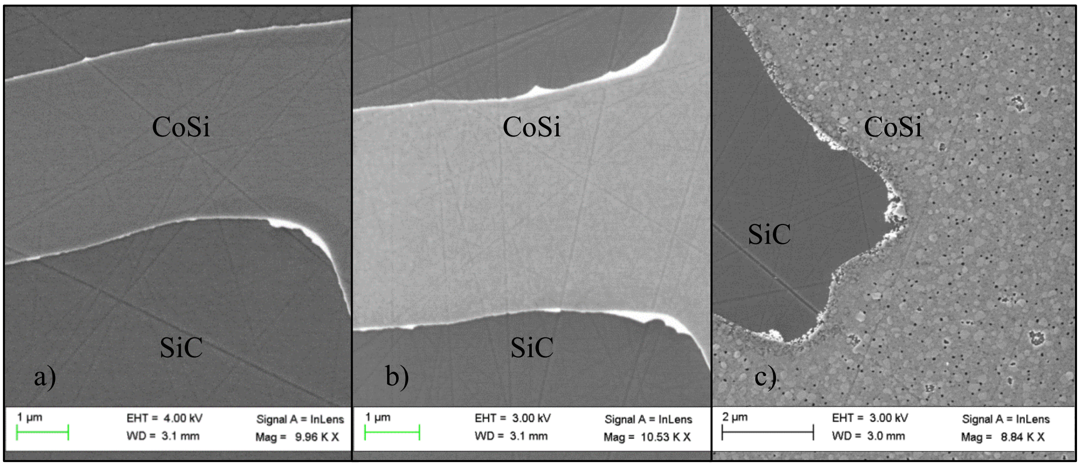

Fig. 5. SEM of sample A: a) prior to RTA b) RTA at 600 °C c) RTA at 950 °C.

whether or not there is an ohmic contact to the SiC substrate, the two probes on the same contact can indicate when the intermixing of the Si and Co gives a conductive silicide instead of metal-semiconductor layers.

The first annealing step was to form silicide out of the deposited layers while the second step concluded the silicidation and made a reaction with the substrate occur. In the deposition the Si:Co ratio was 2.5:1 with an intended shortage of Si forcing a substrate reaction to complete the $CoSi_2$ formation. It is clearly seen in Fig. 3 how the high temperature anneal at 950 °C was needed for an ohmic contact to form though the barriers were narrowed already by the earlier annealing steps at lower temperatures. With two probes on the same contact, the conductivity increased significantly already after RTA at 600 °C, a temperature considerably lower than the 950 °C needed for the ohmic contact formation to SiC, proving the reaction between the deposited layers.

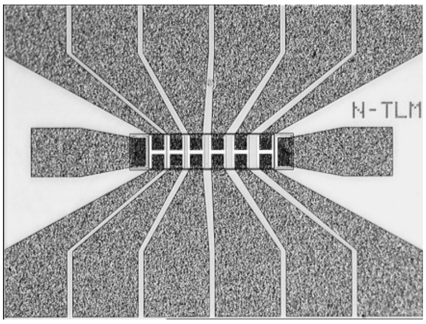

Fig 6. TLM with extended Al pads for measuring or bonding.

SEM of the different annealing steps show smooth surfaces of the contacts up to the 800 °C anneal above which, voids of larger sizes appear in the metal film as seen in Fig. 5.

The annealing tests led to a two-step RTA sequence for sample B consisting of an initial anneal at 600 °C followed by a second anneal at 950 °C with the chamber kept closed under N_2 flow in-between the steps. A TLM structure with larger contacts, 100 µm · 200 µm, was characterized to assure ohmic behavior before an Al top metallization was sputter deposited and wet etched for patterning of extended measurement pads, see Fig. 6. Process details of the samples are summarized in Table 1.

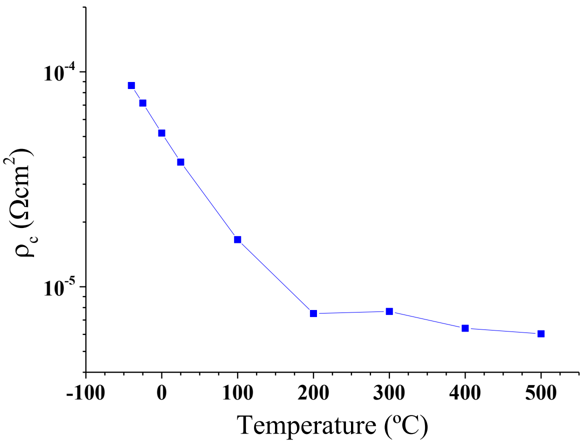

Fig. 7. Specific contact resistivity ρ_c plotted for temperatures -40 °C – 500 °C.

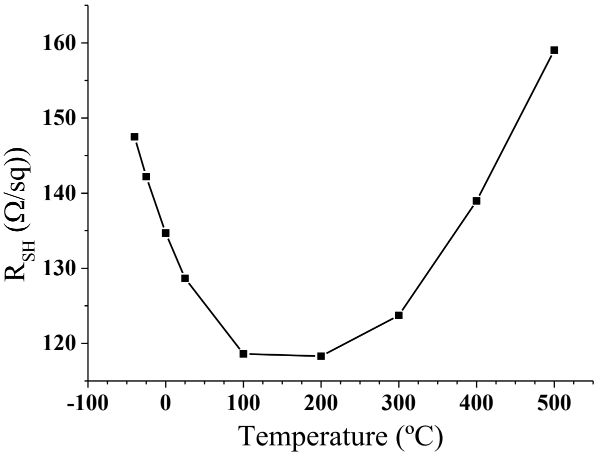

Fig. 8. Sheet resistance R_{SH} for temperatures -40 °C – 500 °C.

Results

Specific contact resistivity, ρ_c. After the final Al metallization, n-type contacts of sample B were characterized from -40 °C to 500 °C by four terminal probing of TLM-structures with contacts sized 50 µm · 100 µm and extended pads (200 µm · 200 µm) for probing, see Fig. 6. At room temperature ρ_c was characterized to $3.8 \cdot 10^{-5}$ Ωcm^2, while a decrease in temperature to -40 °C more than doubled the resistivity. For temperatures above ambient temperature, ρ_c drastically dropped to $7.5 \cdot 10^{-6}$ Ωcm^2 at 200 °C, whereafter a further increase in temperature did not drastically change the resistance as seen in Fig 7 and Table 2.

I-V measurements of the contacts to p-type SiC on sample B did not show ohmic behavior at any temperature, probably related to the low grade of doping in the epitaxial layer of the sample compared to earlier reported $CoSi_2$ contacts to p-SiC (doped to $2 \cdot 10^{19}$ cm^{-3} [2]).

Sheet resistance, R_{sh}. The sheet resistance is proportional to the slope in the TLM measurements and was calculated from the I-V measurements for the same temperature interval as ρ_c above, Fig. 8. As expected the sheet resistance reaches a minima at 200 °C with R_{sh}= 120 Ω/sq whereas higher as well as lower temperatures increase the sheet resistance. The here presented temperature behavior of R_{sh} follows earlier published measurements for n- as well as p-type 4H SiC. The origin is thought to be found in the temperature dependence of the mobility and the dopant ionization that are opposing each other [6].

Table 2. Specific contact resistivity ρ_c and sheet resistance R_{sh}.

	- 40 °C	**25 °C**	**100 °C**	**200 °C**	**300 °C**	**400 °C**	**500 °C**
ρ_c, [Ωcm^2]	$8.6 \cdot 10^{-5}$	$3.8 \cdot 10^{-5}$	$1.7 \cdot 10^{-5}$	$7.5 \cdot 10^{-6}$	$7.7 \cdot 10^{-6}$	$6.4 \cdot 10^{-6}$	$6.0 \cdot 10^{-6}$
R_{sh} [Ω/sq]	145	130	120	120	125	140	160

Summary

Ohmic cobalt silicide contacts have been formed out of sputtered stacked layers of Co and Si. At higher temperatures, 200 – 500 °C little variation is seen in the specific contact resistivity due to temperature which is of interest for high temperature applications.

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