Investigating extremely low resistance ohmic contacts to silicon carbide using a novel test structure

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ABSTRACT

Low resistance contracts to highly doped silicon carbide (SiC) are investigated. Using a novel test structure that is easy to fabricate and easy to use, this paper demonstrates how it is used to reliably determine relatively low specific contact resistivities which vary with heat treatment. The test structure requires no error correction and is not affected by parasitic resistances. Using the test structure, small changes in specific contact resistivity are determined for small temperature changes. Results will be presented and discussed on the application of this novel test structure for nickel to highly doped SiC.

Keywords: Silicon carbide, contact resistance, ohmic contact, specific contact resistivity

1. INTRODUCTION

The compound semiconductor silicon carbide has excellent electrical and physical properties. Like all semiconductor devices, low resistance ohmic contacts to silicon carbide are required to minimise power losses in SiC devices. Specific contact resistivity (ρ_c) is an extremely important parameter, which quantifies this metal to semiconductor ohmic contact. The measurement of ρ_c for ohmic contacts to semiconductor has been reported by a number of people who used transmission line model and circular transmission line model¹⁻⁷.

In this paper, we present a novel test structure for determining ρ_c with experimental results for Ni to SiC contacts. Highly doped epitaxial SiC samples were each coated with 200nm of nickel and patterned using a novel two-electrode ohmic contact test structure. Results obtained for sheet resistance of the active SiC layer agreed with Van der Pauw measurements and like the specific contact resistivity measurements, were consistent across many samples. Sheet resistance was 28 Ω/sq . (independent of heat treatment) and the specific contact resistivity varied with varying heat treatments from low $8.3 \times 10^{-7} \Omega \cdot \text{cm}^2$ to $5.6 \times 10^{-6} \Omega \cdot \text{cm}^2$. The convenience and sensitivity of the test structure allowed for ease of determination of the appropriate heat treatment, to minimise the specific contact resistivity. Materials analysis was conducted to demonstrate the high crystal quality, low surface roughness, and appropriate stoichiometry of the SiC layer. The electrodes fabricated were exact in dimensions and these could be conveniently measured. The accurate measurement of electrode dimensions using a scanning electron microscope resulted in highly consistent results to be determined from electrical measurements using electrodes of different dimensions. Being circular electrodes allowed for accurate fabrication of such electrodes using contact lithography.

2. THE MODEL

The isotropic view of the proposed test structure is shown in Figure 1. It consists three pairs of patterns which have different radii of the central dot r_{01} , r_{02} and r_{03} from left to right. The inner and outer radii r_i and r_o of the outer electrode are the same for each pair. In this paper, the metal electrodes are assumed to be equipotential.

As shown in figure 1, the total resistance R_{T1} , R_{T2} and R_{T3} are measured between the central dot and the outer electrode for each pair of patterns.

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Figure 1. The isotropic view of the proposed test structure. The radii of the central dot from left to right are r_{01} , r_{02} and r_{03} respectively. The inner and outer radii for each pair of the patterns are the same which are r_i and r_o .

As shown in equation (1), for each pair of the patterns, the total resistance R_T consists of the contact resistance of the central dot R_{C0} , the parasitic resistance of the semiconductor ring R_P and the contact resistance of the outer electrode R_{C1} .

$$R_T = R_{C0} + R_P + R_{C1} \quad (1)$$

As reported by Reeves⁸, the analytical equations for R_{C0} , R_P and R_{C1} are

$$R_{C0} = \frac{R_{SH}}{2\pi\alpha r_0} \frac{I_0(\alpha r_0)}{I_1(\alpha r_0)} \quad (2)$$

$$R_P = \frac{R_{SH}}{2\pi} \ln\left(\frac{r_1}{r_0}\right) \quad (3)$$

$$R_{C1} = \frac{R_{SH}}{2\pi\alpha r_1} \frac{[I_1(\alpha r_1')K_0(\alpha r_1) + I_0(\alpha r_1)K_1(\alpha r_1')]}{[I_1(\alpha r_1')K_1(\alpha r_1) - I_1(\alpha r_1)K_1(\alpha r_1')]} \quad (4)$$

Hence, for these three pairs of the patterns, we have

$$R_{T1} = R_{C01} + R_{P1} + R_{C1} \quad (5)$$

$$R_{T2} = R_{C02} + R_{P2} + R_{C1} \quad (6)$$

$$R_{T3} = R_{C03} + R_{P3} + R_{C1} \quad (7)$$

Substitute equation (2)-(4) to (5)-(6), we have

$$R_{T1} - R_{T2} = \frac{R_{SH}}{2\pi} (F + \ln x) \quad (8)$$

where $F = \frac{I_0(\alpha r_{01})}{\alpha r_{01} I_1(\alpha r_{01})} - \frac{I_0(\alpha r_{02})}{\alpha r_{02} I_1(\alpha r_{02})}$ and $x = \frac{r_{02}}{r_{01}}$

Also, we have

$$R_{T1} - R_{T3} = \frac{R_{SH}}{2\pi} (F' + \ln y) \quad (9)$$

where $F' = \frac{I_0(\alpha r_{01})}{\alpha r_{01} I_1(\alpha r_{01})} - \frac{I_0(\alpha r_{03})}{\alpha r_{03} I_1(\alpha r_{03})}$ and $y = \frac{r_{03}}{r_{01}}$

Note that α is the inverse of the transfer length L_t

$$\alpha^2 = \frac{R_{SH}}{\rho_c} \quad (10)$$

Then we can get

$$K = \frac{R_{T1} - R_{T3}}{R_{T1} - R_{T2}} = \frac{F' + \ln y}{F + \ln x} \quad (11)$$

Since K can be determined experimentally and x and y can be determined by selecting appropriate r_{01} , r_{02} and r_{03} , we can plot K as a function of αr_{01} using equation (11). Also we can plot αr_{01} as a function of F or F' using equation (8)-(9).

Figure 2. Ration K versus αr_{01} for given rations of radii.

For experimental determined K , we can pick up a value for αr_{01} in figure 2. Point A is an example data. Using this value in figure 3, we can get either F or F' . Points A' and A'' represent point A in figure 2. According to equation (8)-(9), we can get the sheet resistance R_{SH} . With known R_{SH} and α , using equation (10), specific contact resistivity ρ_c can be found.

Figure 3. F and F' versus ar_{01} for given ratios of radii.

3. EXPERIMENTAL

Experimental measurements were performed on Ni to SiC ohmic contacts. The n-type SiC films were deposited to a thickness of 300 nm on Si substrate. The wafers were then cleaned using a sequence of rinses in acetone, isopropyl alcohol and deionised water which were alternated with drying in a stream of nitrogen gas. A Ni layer with 200 nm thickness was then deposited on the SiC layer by electron beam evaporation. AZ 1521 photoresist was then spin coated over the samples followed by a soft baking at 95 °C for 90 seconds. The samples were then exposed to UV light for 10 seconds. After the photoresist was developed in 1: 4 AZ 400 for 15 seconds, the uncovered Ni was then removed by wet etching using a Ni etchant for 30 seconds at room temperature. The samples were then cleaned in acetone followed by IPA rinse and dried using nitrogen gas.

Figure 4 shows the optical micrographic of the proposed test structure fabricated on n-type SiC.

Figure 4. Optical micrographic of the proposed test structure fabricated on n-type SiC. The radii of the central dot from left to right are 5 μm , 7.5 μm and 17.5 μm respectively.

4. RESULTS AND DISCUSSION

Current-voltage characteristics of as deposited Ni to SiC contacts are linear. Table 1 summarizes the results for the patterns where the dimensions vary from $r_{01} = 5.0 \mu\text{m}$, $r_{02} = 7.5 \mu\text{m}$, $r_{03} = 17.5 \mu\text{m}$ to $r_{01} = 9.0 \mu\text{m}$, $r_{02} = 13.5 \mu\text{m}$, $r_{03} = 31.5 \mu\text{m}$. The measurements were performed using 1 mA current and two manipulators are used to keep the outer ring electrodes equipotential.

Table 1. Experimental results using the proposed test structure for determining the specific contact resistivity for as deposited Ni to SiC ohmic contacts

Patterns	α_{01}	$R_{SH} (\Omega/\text{sq.})$	$\rho_c (\Omega \cdot \text{cm}^2)$
1	3.02	28.2	2.4×10^{-6}
2	4.35	30.4	1.2×10^{-6}
3	3.63	29.4	1.3×10^{-6}
4	2.46	28.3	2.4×10^{-6}
5	3.09	28.5	3.6×10^{-6}
6	3.72	29.3	1.2×10^{-6}
7	4.08	28.4	8.3×10^{-7}
8	4.08	28.4	2.4×10^{-6}
9	1.93	27.5	5.7×10^{-6}
10	3.60	29.7	3.2×10^{-6}

It is clearly that the value of R_{SH} is approximately 28 $\Omega/\text{sq.}$ which is very close to 27 $\Omega/\text{sq.}$ that determined using Van der Pauw measurements. Specific contact resistivity varies from $8.3 \times 10^{-7} \Omega \cdot \text{cm}^2$ to $5.7 \times 10^{-6} \Omega \cdot \text{cm}^2$ which is highly acceptable and extremely low for metal to SiC ohmic contacts. This small variation also give the confidence in the values obtained by the proposed test structure.

5. CONCLUSION

Extremely low specific contact resistivity of as deposited Ni to SiC ohmic contacts were obtained by using a novel test structure which consists of a serious of circular electrode pairs. The sheet resistance was also determined by this test structure and it has been verified by Van der Pauw measurements. The lowest value of the specific contact resistivity obtained in the experiment is $8.3 \times 10^{-7} \Omega \cdot \text{cm}^2$. The results have shown that for the appropriate geometries, this test structure is accurate and convenient for determine and since no error correction required and no complicated equations have to be solved.

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