Precise Resistivity Measurement Independent Of Contact Resistance Influence And Its Applications

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Abstract : A universal four-point contact measurement method, has an advantage of non-existence of contact resistance, is demonstrated by the experiments with carbon nanotubes and ZnO nanowire. Ti/Au and Pt are tried to compare the influence of contact resistance between two different metals. These metals are selected to make Ohmic contact and Schottky contact originated from their different work functions. For precise experiments, Ti/Au and Pt are separately evaporated to form doubke 'four-point contact electrodes' on CNTs or ZnO, and the voltage-current characteristics are measured. This method can be applied to universal resistivity measurement for nanotubes and nanowires.

Key Words : contact resistance, carbon nanotube, ZnO nanowire

1. Introduction

In recent years, a four-point probe measurement method has been preferred to a two-point probe method for the resistivity measurements of the conductive materials because it can exclude the contact resistance between two different materials [1]. Although, in real measurements using a four-point probe method, the contact resistance appears due to its systematic error. Accordingly a universal four-point probe method was proposed [2].

We demonstrated an advantage of the universal four-point probe method and applied it to ZnO nanowires experimentally. To verify that the method can exclude the influence of contact resistance, we selected some metals as electrodes for Ohmic contacts and Schottky contacts deliberating their work functions.

2. Experiment

The universal four-point contact method to measure the resistivity of nanowire with diameter D and length L are shown in Fig 1. Voltage-Current measurements between each metal pads are performed and the resistivity of nanowire can be calculated with the following equation.

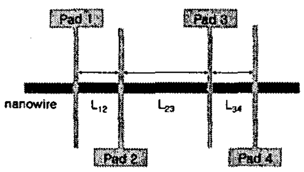

Fig 1. Scheme of four-point contact

The equivalent circuit of contact between metal pad 1 and 2 is shown in Fig 2. The voltage drop caused by the Schottky barrier are V_1, V_2 , the contact resistance are R_{C1}, R_{C2} and the real resistance of nanowire is R_{L12}.

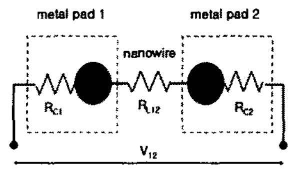

Fig 2. Equivalent circuit of contact

$$R_{12+} = \frac{(R_{L12}+R_{C1}+R_{C2})}{(V_{12}-V_1-V_2)}V_{12}, \quad R_{12-} = \frac{(R_{L12}+R_{C1}+R_{C2})}{(V_{12}+V_1+V_2)}V_{12}$$

$$R_{12} = (R_{L12}+R_{C1}+R_{C2}) = \frac{2}{1/R_{12+}+1/R_{12-}}$$

$$\Delta R = (R_{14}-R_{12})+(R_{32}-R_{34})$$
$$= (R_{C4}-R_{C2})+(R_{L14}-R_{L12})+(R_{C2}-R_{C4})+(R_{L32}-R_{L34})$$
$$= (R_{L14}-R_{L12})+(R_{L32}-R_{L34})$$

$$\Delta L = (L_{14}-L_{12})+(L_{32}-L_{34}) = 2L_{32}$$

$$\therefore \ \rho = S\frac{\Delta R}{\Delta L} = S\left[(R_{L14}-R_{L12})+(R_{L32}-R_{L34})\right]/2L_{32}$$
$$= S\left[(R_{14}-R_{12})+(R_{32}-R_{34})\right]/2L_{32}$$

$$\textit{where } S = \pi\left(\frac{D}{2}\right)^2, \textit{ D is the diameter of nanowire}$$

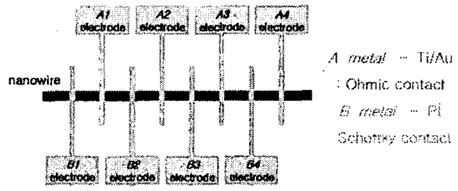

Fig 3. Double four-point contact

The work function of ZnO nanowire which has n-type property, is 4.95eV [3]. Generally, Ti/Au (A electrode) with

4.33eV work function makes Ohmic contact and Pt (B electrode), with 5.65eV work function makes Schottky contact to ZnO nanowires because of their electronic properties [4].

The independence of the contact resistance irrespective of the contact type such as Schottky or Ohmic contacts relative to metal work functions was shown. To exclude the individual properties of nanowires, Ti/Au and Pt were separately evaporated and double 'four-point contact electrodes' were made on a ZnO nanowire after e-beam lithography process.

3. Result and Discussion

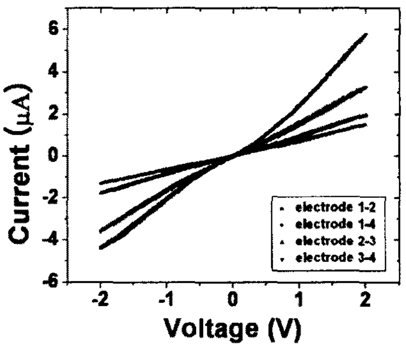

Fig 4. Voltage-current characteristics between each electrodes

The measurements of resistance were performed with HP4140B pA electrometer. The resistance of each electrodes are 0.41 X 10^6 Ω (electrode 1-2), 1.45 X 10^6 Ω (electrode 1-4), 1.09 X 10^6 Ω (electrode 2-3), 0.60 X 10^6 Ω (electrode 3-4). The diameter of nanowire is 45 nm and the distance between the electrode 2-3 is 1 um.

$$\begin{aligned}\rho &= S\frac{\Delta R}{\Delta L} = S\frac{[(R_{14}-R_{12})+(R_{32}-R_{34})]}{2L_{32}} \\ &= \pi(\frac{45\times10^{-9}}{2})^2\frac{(1.45-0.41+1.09-0.60)\times10^6}{2\times10^{-6}} \\ &= 1.22\times10^{-3}\end{aligned}$$

The calculated resistivity is 1.22 X 10^{-3} Ωm. In contrary, the measured resistivity with traditional four-point contact method is 1.47 X 10^{-4} Ωm, so we could get more precise data with this universal method.

4. Conclusion

We measured the resistivity of ZnO nanowire with a universal four-point contact method to exclude the systemic error of the traditional four-point contact method. Due to the advantage of the universal four-point contact method, the discrepancy of the contact resistance between ZnO nanowire and Ti/Au, Pt electrodes which make Ohmic and Schottky contact could be diminished. This method can be applied to universal resistivity measurements for nanotubes and nanowires.

Acknowledgement

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Reference

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