Rectifying diode made of individual gallium nitride nanowire

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Abstract

We have fabricated a Schottky-junction diode, utilizing gallium nitride (GaN) nanowire, and studied its electrical transport properties. Two kinds of metal electrodes, Al and Ti/Au, were incorporated into an individual GaN nanowire synthesized by chemical vapor deposition (CVD) method. A Schottky-barrier junction was formed in the Al electrode while ohmic contact was formed in the Ti/Au electrode. The measured current-voltage characteristic exhibited clear rectifying behavior and no reverse bias breakdown was observed up to the measured voltage, -5 V.

Key words: nanowire; Schottky diode; GaN

1. Introduction

One dimensional nano-structured crystals, such as nanowires and nanotubes, can be used not only to widen our knowledge on the physical phenomena at low dimensional systems but also as a building block of nano devices. Carbon nanotube (CNT) is one of the best known and most extensively studied systems. A lot of experimental and theoretical studies have been made on the electrical transport properties of CNT and a variety of CNT-based electronic devices have been proposed and realized [1]. For the device applications of CNT, controlling electronic properties of CNT is required. But there is no established method to control the chirality of CNT which is known to determine its electronic properties. In this respect, semiconducting nanowires, like Si, GaN, and GaAs, have great advantage for device applications [2]. Their electrical transport properties can be easily modified by impurity doping and there are well known recipes of ohmic contacts. In spite of such advantages, a few studies have been made on the electrical transport properties of semiconducting nanowires.

In this paper we report the fabrication and the characteristics of one of the basic electronic device elements, Schottky diode, by using GaN nanowire synthesized by CVD method. We have incorporated two kinds of metal electrodes, Al for Schottky-barrier junction and Ti/Au for ohmic contact, into individual GaN nanowire.

2. Experiment and results

High quality GaN nanowires were synthesized using Ni catalyst by direct reaction of the mixture of gallium metal and GaN powder with flowing ammonia at 1000 C using thermal CVD [3]. The individual GaN nanowire was prepared on a Si substrate with a 500 nm-thick thermally-grown SiO_2 layer. The patterns for electrical leads were generated by using electron beam lithography onto the selected GaN nanowire and then 20 nm of Ti and 50 nm of Au were deposited successively on the contact area by thermal evaporation. The diameter of nanowire is about 50 nm. Ti is known as good low ohmic contacted material to GaN after a optimum annealing process. Ohmic contacts between the GaN nanowire and the Ti/Au electrodes were achieved by a rapid thermal annealing at 400-500 C for 30 s. Af-

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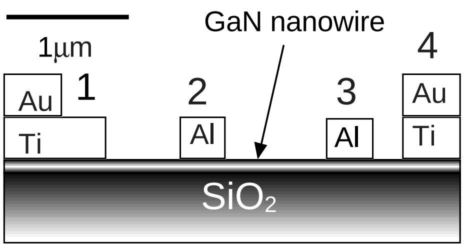

Fig. 1. The schematic side view of a GaN nanowire with two ohmic contacted Ti/Au (1 and 4) and two Schottky contacted Al electrodes (2 and 3)

ter establishing ohmic contacts to GaN nanowire, we deposited Al metal to form a Schottky barrier onto the pre-patterned nanowire by thermal evaporation. Fig. 1 shows the schematic side view of a GaN nanowire with two ohmic contacted Ti/Au (1 and 4) and two Schottky contacted Al electrodes (2 and 3).

Inset of Fig. 2 shows the current-voltage (I-V) characteristics between the two electrodes, 1-4 at room temperature. It shows a highly linear behavior with the total resistance, $R = 2R_C + R_{NW} \approx$ 450 kΩ, where R_C is the contact resistance and R_{NW} is the resistance of nanowire itself. Hence the resistance per each contact should be smaller than 225 kΩ with contact area, 50 nm × 1000 nm. It gives a contact resistivity smaller than 1.12×10^{-4} Ω m^2 at room temperature.

Figure 2 shows the I-V characteristics between Al electrode (2) and Ti/Au electrode (1), exhibiting clear rectifying behaviors with turn-on voltages of 0.4 and 1.1 V at room temperature and 10 K, respectively. No reverse bias breakdown voltage was observed over the measured range, -5 V. Since a positive bias voltage applied to the Al electrode, the observed I-V curve represents n-type Schottky diode characteristics. This means that our GaN nanowire should be an n-type semiconductor, which is consistent with the recent experimental results [3]. We fitted the I-V curve at room temperature to the generalized diode equation as follows [4],

$$I = I_0 \{\exp(e(V - V_{th})/\eta k_B T) - 1\} \quad (1)$$

where I_0 is the reverse bias saturation current, V_{th} is the forward bias threshold voltage defined by the voltage where the current begins to increase in the forward direction, and η is the ideality factor, which is close to unity if thermionic emission is the dominant transport mechanism.

The solid line in Fig. 2 represents the fitted curve. The obtained η value from the fit is about 17.8, which is much larger than that of the ideal diode. Since we have done no thermal annealing process for Al electrodes, GaN would not react with the Al to form conducting interface. Large η value may result from the existing insulating AlO_x interface layer during the thermal evaporation. Another possible explanation is that evaporated Al attracts N in GaN, forming an insulating AlN layer at the interface. The insulating interfacial layer is known to cause significant departure of η from unity. Such large η values were also reported in metal/semiconductive polymer Schottky devices [5].

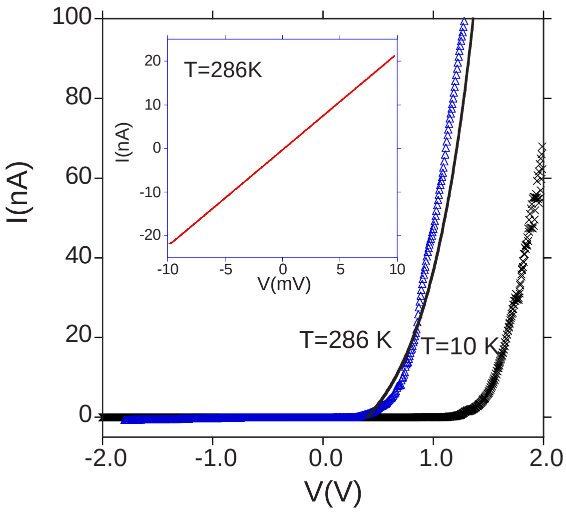

Fig. 2. The I-V characteristics between Al electrode (2) and Ti/Au electrode (1) at room temperature and 10 K. The solid line represents the fitted curve to the generalized diode equation. Inset: the I-V curve between the two electrodes, 1-4 at room temperature.

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