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Preparation of ohmic n-type cubic boron nitride contacts

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Abstract
Ohmic electrodes in the form of n-type (Si-doped) cubic boron nitride (c-BN) bulk crystals were fabricated by utilizing a covering technique, depositing Ti(10 nm)/Mo/(20 nm)/Pt–Au(200 nm) ohmic contact metal on both the sides of the c-BN substrate. The size of the specimen electrode was $100 \times 100\ \mu m^2$ on one side and $300 \times 300\ \mu m^2$ on the other side. Measurements on the specimen were made using a specially made device. Linear current–voltage characteristics were obtained. It is considered that the contact between the Ti- and Si-doped c-BN was ohmic.

1. Introduction

Materials made from tetrahedrally bonded light elements, such as diamond and cubic boron nitride (c-BN), may be useful as large-energy-gap semiconductors [1]. As c-BN is an artificial material [2] and sample sizes are limited, its electrical properties—such as its mobility—have not been studied in detail.

Since Wentorf [3] first synthesized c-BN from hexagonal boron nitride (h-BN) under high temperature and high pressure (HTHP) with the help of a suitable catalyst, in 1957, a lot of characteristics of c-BN have been studied by scientists. They found that c-BN has many excellent properties, such as being the simplest III–V compound and one that is stable under high pressure and metastable to about 1300 °C at 1 bar [4], and has the widest energy gap ($>$6.4 eV [5], indirect [6, 7]) among IV and III–V materials. Electronic devices made of c-BN are therefore likely to be operative at high temperatures. Unlike diamond, which cannot easily be made into an n-type semiconductor, c-BN can be made into a p-type (Be-doped) or n-type (S- or Si-doped) semiconductor [8] if suitable impurities are added. It has been reported that a p–n homojunction diode has been made by a conventional HTHP [1] method for the first time, but ohmic c-BN electrodes have not been made. Preparation of ohmic electrodes is essential if c-BN is to be used in any electronic devices.

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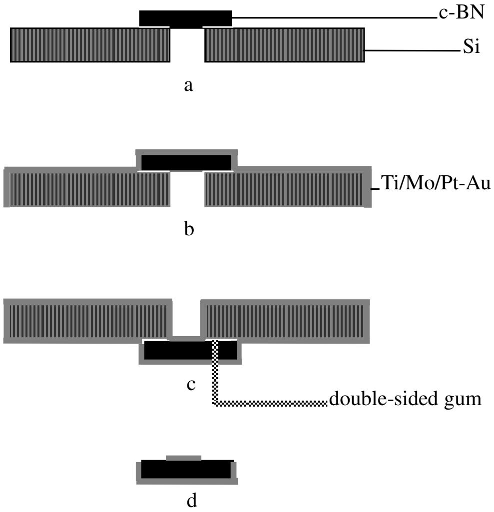

Figure 1. The procedure of fabrication of the ohmic electrodes of n-type c-BN. (a) Si-doped c-BN was stuck on a silicon flat with double-sided gum which has a hole of diameter 100 μm. (b) Deposition of the Ti/Mo/Pt–Au ohmic metal onto n-type c-BN on the front. (c) Deposition of Ti/Mo/Pt–Au ohmic metal onto n-type c-BN on the back. (d) Cleaning of the n-type c-BN with acetone.

In the present work, we describe the preparation of ohmic electrodes of n-type c-BN. As the size of the c-BN samples available is very small (300 $\times$ 300 μm^2), we have utilized a covering technique to fabricate an ohmic electrode for the first time (the size of the specimen electrode was 100 $\times$ 100 μm^2 on one side and 300 $\times$ 300 μm^2 on the other side) and measured its current–voltage (I–V) characteristics by means of a specially made device. Linear I–V characteristics were obtained; it is considered that the contact between the Ti- and Si-doped c-BN was ohmic.

2. Experimental

The c-BN specimens were fabricated by the conventional HTHP method.

The starting material was h-BN together with a solvent. After exposure to a pressure of 4.0–6.0 GPa and a temperature of 1400–1900 °C for 10–20 min, c-BN single crystals were obtained. The size of the crystals used was about 300 μm. Si-doped n-type c-BN was obtained by the conventional high-temperature diffusion method. Prior to diffusion, the c-BN crystals were cleaned with aqua regia and the organic solvents toluene, alcohol and acetone; this was followed by a deionized water rinse and drying with an infrared lamp. The c-BN crystals were covered by fine silicon power. The diffusion conditions were: pressure: 10^{-3} Torr; specimen temperature: 850 °C; diffusion time: 5 h.

The Si-doped n-type c-BN was cleaned with an acid mixture of HF and HNO_3; this was followed by a deionized water rinse and drying with an infrared lamp. The procedure of fabrication of the ohmic electrodes from n-type c-BN is illustrated in figure 1. First, Si-doped c-BN was stuck on a silicon flat with double-sided gum which had a hole of diameter 100 μm (figure 1(a)). The ohmic electrode of Ti(10 nm)/Mo(20 nm)/Pt–Au(200 nm) was deposited by using RF magnetron sputtering onto the front of the n-type c-BN single crystal (figure 1(b))

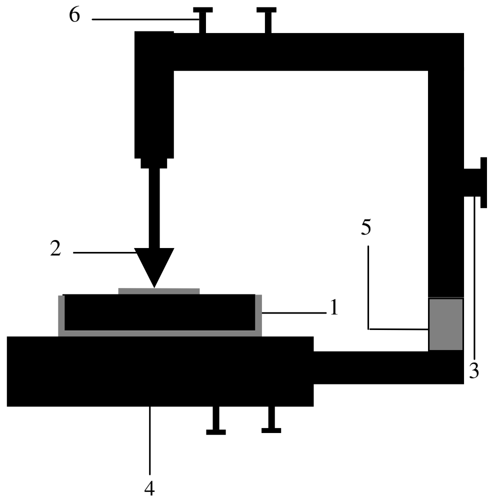

Figure 2. The device used for measuring the I–V characteristics of the n-type c-BN. 1: sample; 2: probe; 3: fluctuation rotational shear; 4: metal plate; 5: insulator material; 6: terminal.

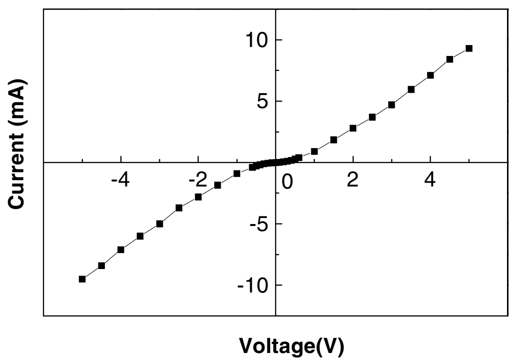

Figure 3. I–V characteristics of the Ti/Mo/Pt–Au electrodes on the Si-doped c-BN.

and onto the back of the c-BN single crystal (figure 1(c)). The specimen was cleaned with the organic solvents alcohol and acetone; this was followed by a deionized water rinse and drying with an infrared lamp (figure 1(d)). The size of the specimen was $300 \times 300\ \mu m^2$ on the front of the c-BN and $100 \times 100\ \mu m^2$ on the back of the c-BN. The specimen was then annealed at 300 °C in air for 10 min to achieve ohmic metal alloying. To establish the ohmic nature of the Ti/Mo/Pt–Au contact to Si-doped c-BN, I–V characteristics were measured between the electrodes using a specially made device (figure 2).

3. Results and discussion

The resistance of the ohmic contact of Ti(10 nm)/Mo(20 nm)/Pt–Au(200 nm) to Si-doped c-BN is illustrated in figure 3. The I–V characteristic is nearly linear, so it is considered that the contact between the Ti- and Si-doped c-BN was an ohmic contact.

The results indicate that the device is of great importance. The quasilinear line has inflection points near the central hole, relating to the low level of Si doping of the c-BN bulk

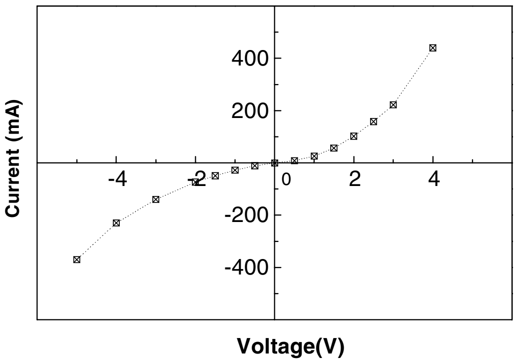

Figure 4. *I–V* characteristics of the Ti/Mo/Pt–Au electrodes on the Si-doped c-BN before the annealing of the Si-doped c-BN.

crystal and restrictions of the measuring instrument. The *I–V* characteristics of Si-doped n-type c-BN can be improved by enhancing the level of Si doping of the c-BN bulk crystals.

The *I–V* characteristics of the Ti/Mo/Pt–Au electrodes on the Si-doped c-BN before the annealing of the Si-doped c-BN are shown in figure 4. As can be seen from figures 3 and 4, the *I–V* characteristics are obviously different: a curve and a line. The results indicate that the contact between Ti- and Si-doped c-BN was ohmic after the c-BN was annealed.

4. Conclusions

Ohmic n-type (Si-doped) c-BN bulk crystal electrodes were fabricated by utilizing a covering technique, depositing Ti(10 nm)/Mo/(20 nm)/Pt–Au(200 nm) ohmic contact metal on both the sides of the c-BN substrate. The size of the ohmic electrode was $300 \times 300\ \mu m^2$ on the front of the c-BN and $100 \times 100\ \mu m^2$ on the back of the c-BN.

To establish the ohmic nature of the Ti/Mo/Pt–Au contact for the Si-doped c-BN, *I–V* characteristics were measured between the electrodes. As linear *I–V* characteristics were obtained, it is considered that the contact between the Ti- and Si-doped c-BN was ohmic.

References

[1] Mishima O, Tanaka J, Yamaoka S and Fukunaga O 1987 *Science* **238** 181
[2] Tomikawa T, Nishibayashi Y and Shikata S 1994 *Diamond Relat. Mater.* **3** 1389
[3] Wentorf R H Jr 1961 *J. Chem. Phys.* **34** 809
[4] DeVries R C 1972 *Report No* 72 CRD 178 (General Electric Corporation, Schenectady, NY)
[5] Crenko R M 1974 *Solid State Commun.* **14** 511
[6] Zunger A and Freeman A J 1978 *Phys. Rev.* B **17** 2030
[7] Huang M Z and Ching W Y 1985 *J. Phys. Chem. Solids* **46** 977
[8] Wentorf R H Jr 1962 *J. Chem. Phys.* **36** 1990